Digital Technology Adoption and Potential in Southeast Asian Agriculture

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ABSTRACT

While the rural agriculture sector has traditionally been seen as backward relative to the urban industrial and services sectors, it is a potential "low-hanging fruit" ripe for a much-needed digital transformation for agricultural development. ASEAN has seen a U-turn in progress in addressing undernourishment as early as 2014–16, owing to multiple factors. These include climate change which impacts have led to a slowdown in agricultural yield growth amidst growing consumption requirements. Digital technologies are important in adapting the agriculture sector to climate change and rising demand for it to serve as a key sector for food security, income, trade, and employment in the region. However, adoption of digital technologies in agriculture within the region is still relatively nascent, partly because of a general lack of understanding of such technologies and how they contribute to agricultural development. Also lacking is a common framework for understanding and classifying the relevance of such technologies. Thus, this article proposes a common framework and narrates how it was developed and used in facilitating discussions that helped develop the 2021 *ASEAN Guidelines on Promoting the Utilization of Digital Technologies for ASEAN Food and Agricultural Sector*. We draw insights from our earlier work on the state of adoption of digital technologies in agriculture in the region and give an overview of key challenges and policy opportunities for scaling up.

Keywords: food security, agricultural technology, technological change, Southeast Asia, SEA
JEL codes: Q16, 033, N55

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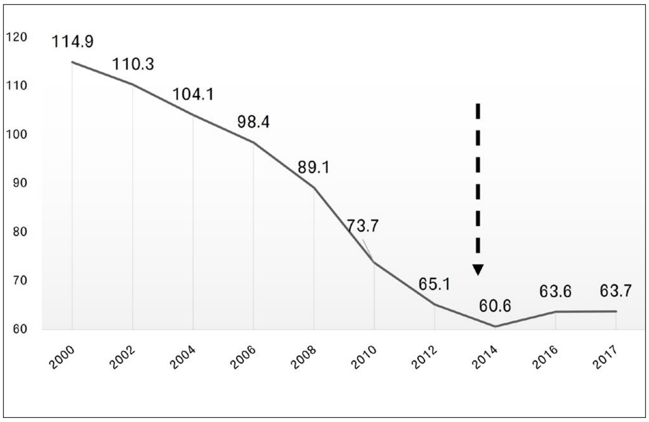
INTRODUCTION

Can digital technologies play a more prominent role in addressing the ongoing challenges faced by Southeast Asia's (SEA's) agriculture in serving as a key sector for food security, income, trade, and employment in the region?

Since the first green revolution of the '60s to the '80s, agriculture and agri-food systems in SEA have transformed much. Agriculture has modernized by using more fertilizer and pesticides and improved crop varieties (Teng and Adriano 2021). Agri-food systems have also transformed from local/domestic supply chains into global supply chains. The "farm-to-table" process has diversified too through supermarkets, replacing the local "mom and pop" shops, wet markets, and *sari-sari* (Tagalog for variety stores) as part of the "supermarket revolution" in the 1990s (Reardon et al. 2003).

Although addressing undernourishment in the region had significantly improved in 1990–2014, food security in SEA saw a U-turn in the past decade (Montesclaros 2020; 2021). Undernourishment saw a falling trend in 1990–2014 and started increasing in 2014–16 (Figure 1). This owes to challenges in increasing productivity to raise total production and meet growing agricultural demand amidst climate change, exacerbated by COVID-19 and Russia's war with Ukraine.

Figure 1. Onset in 2014–16 of U-turn in undernourishment in SEA (in number of people undernourished, millions)



Source: Based on data of the Food and Agriculture Organization (FAO) compiled in Montesclaros (2020)

Such U-turn is telling of the slowing progress in agricultural productivity and the agri-food system in most SE Asian countries owing to climate change. This is evidenced during the late 1990s through the early 2000's by yield plateaus in crops and significant yield gaps between potential yield and actual farmers' yield. A significant proportion of smallholder farmers, (the main group of farmers producing food in SEA), remain technologically unsophisticated (Marie 2022). This contrasts greatly with food-producing farmers in North America and Europe adopting precision agriculture and smart farming techniques for higher yields—consequently, surpluses for export trade.

On one hand, governments in SEA aspire for agriculture to achieve many goals such as assuring food security, creating rural livelihoods, earning foreign exchange through growing industrial and exports crops like rubber and palm oil, maintaining rural communities, and providing ecological and social services. Some of these goals are common to other regions but in SEA, there is uneven achievement of these goals. For example, in general, industrial crops are highly efficient in deploying production technology and are well managed, often in relatively large plantation units. Yet, most of SE Asian countries continue to face challenges in achieving a high level of food security, stably (Economist Impact 2022), with low—and in some cases declining—self-sufficiency levels for food crops, and, correspondingly, increasing import dependency ratios (Dy et al. 2023). Rural livelihoods remain disadvantaged compared with that of urban workers and professionals, especially when smallholder farmers do not see their standard of living improve relative to their urban counterparts.

With these challenges, "knowledge-intensive technologies" are suggested to help improve farmers' efficiency of input use (Teng 2017) and that a new category of farm advisers may be needed in the form of "agropreneurs" (Ra, Ahmed, and Teng 2019) who are tech-savvy and can timely advise smallholders. This has led to a phenomenon where a younger generation of new stakeholders, many of whom are children of farmers, have returned to the countryside to help the aging rural population use new technologies, just like in China (Min, Waibel, and Huang 2017), which can potentially be achieved in SEA as well.

Transforming agriculture and agri-food systems in SEA would need to find an approach that can reach many farmers evenly and ensure that smallholder farmers participate in supply chains. Digital technologies are highly hoped to achieve this.

CHALLENGES REQUIRING PATH-BREAKING SOLUTIONS

In discussing how digital technologies contribute to transforming agriculture, it is first necessary to set the stage by briefly summarizing the key challenges faced by agriculture in SEA. From there, specific challenges and problem areas may be identified. Table 1 shows statistics that are relevant to agriculture and food security in the ASEAN member states (AMS).

SE Asian agriculture faces many challenges common to other world regions. These arise from climate change, degrading and declining land and freshwater resources, pests and diseases, declining crop productivity, high cost of inputs, declining rural labor force, and aging farmers.

Impacts of Climate Change on Crop Productivity and Total Production

ASEAN plays a vital role in producing and supplying important food items in global food supply chains.[1] In the first decade of the green revolution, crop yield growth in rice and wheat exceeded the growth in demand per capita attributable to population growth, but this has now reversed. That yield growth is now exceeded by the growth in demand has become an important issue for Asian countries to maintain their food

1 From its arable land area of approximately 70 million ha, ASEAN has the world's two top consistent rice exporters (Thailand and Vietnam), responsible on average for over 40 percent of the world's exported rice. ASEAN countries remain among the top three exporting countries of pineapple, banana, mango, sugar crops, coffee, cashew nuts, and cassava. The region's semi-permanent to permanent agricultural land use has made it the world's top producer and exporter of palm oil, coconut, and rubber (Montesclaros and Teng 2021).

Table 1. Agricultural land use and related statistics in ASEAN

Country	Agricultural Land % of Total Land 2017	Arable Land, % of Agricultural Land 2020	Permanent Crops % of Agricultural Land 2020	Employment in Agriculture, % of Total Employment, 2021	Agriculture, % of GDP 2021	Urban Population % of Total 2021	GNI Per Capita July 2019
Brunei	2.5	0.8	1.1	1.3 (2020)	1.2	77.6	32,230
Cambodia	31.5	22.0	2.3	33.1 (2019)	24.3	23.4	1,530
Indonesia	33.2	14.0	13.3	28.3	13.8	53.3	4,050
Lao PDR	10.4	6.7	0.6	31.3 (2017)	18.1	35.0	2,540
Malaysia	26.1	2.5	22.7	10.3	9.7	75.6	11,260
Myanmar	19.6	16.9	2.31	45.3 (2019)	21.4 (2019)	33.0	1,270
Philippines	41.7	18.7	18.7	24.2	10.1	46.9	3,850
Singapore	0.9	0.8	0.0	0.8	0.0	100.0	58,060
Thailand	43.3	32.9	10.6	32.9	8.8	52.3	7,250
Timor Leste	25.6	10.4	No data available	30.2 (2016)	13.8 (2020)	30.6	2,050
Vietnam	39.5	21.6	15.7	28.9	12.4	34.2	3,280

Source: ASEANstats 2022; ADB 2022

security, especially for a staple like rice (Yuan et al. 2022).

Although the AMS have some food production systems with increasing productivity, such as those for oil palm, in many others, productivity growth has been declining. Such slowdowns have been interpreted variously as indications of declining soil health, pests and diseases, negative externalities of agricultural practices, climate change effects, among other things (Montesclaros and Teng 2021). Climate change puts additional pressure on natural resources and food security as expressed through higher and more variable temperatures, changes in precipitation patterns, and increased occurrences of extreme weather events. Rising sea levels have also led to increased salinization in river deltas and lakes, further reducing freshwater availability.

SEA's coarse grains grew faster in 1990–2010 than in 1970–90, indicating, to some extent, technology transfer from East Asia. Further evidence of the steady decline in average aggregate yield growth of many food security crops over the years was documented by Grassini, Eskridge, and Cassman (2013). Data from 1960–2010 also showed observable yield plateau among large producers of cereal (Montesclaros and Teng 2021). For example, the average rice yields are often only half of the potential yield. Such yield gaps exist in most crops, and a key challenge in food security is how to reduce the gap between potential and actual yield, along with reducing postharvest losses and waste. Even with climate adaptation, Asia's production of wheat and rice has been projected by the International Food and Policy Research Institute to be 14 and 11 percent lower, respectively, in 2050 relative to 2000 (Teng et al. 2015).

Unsustainable Natural Resource Use

Agriculture is a natural resource-extractive sector, relying mainly on land, water, forestry, and biodiversity for its outputs. The demand for both food and nonfood agri-based produce, such as feed, energy, and industrial raw materials is rising significantly, and will continue in the future. With sustained positive economic growth, changing food and natural resource-based consumption and demand patterns across the region and globally, demand for meat, other high value crops, and plantation crops will be increasing. These compete with cereal staples for scarce land and water resources, thus compounding the challenges relating to increasing production at a pace that continues to meet future demand (Teng and Adriano 2021).

Land, a key asset in agricultural production, has been declining in hectarage and in quality.[2] Between 1970 and 2011, agricultural land area in ASEAN increased substantially from 20.2 to 29.4 percent (FAOSTAT in Teng and Oliveros 2017). However, arable land area in ASEAN, ranging from a low of 0.8 percent of total land area in Singapore to a high of 33 percent in Thailand, is declining in all countries (see Table 1). This is due to demand from other uses, such as housing and industrial infrastructure. The average per capita arable land area in ASEAN is only 0.12 ha (ADB 2022). In addition, a further pressing environmental problem is rapid soil erosion and land degradation, or the deterioration of land condition resulting in the loss of its productive capacity (Teng and Adriano 2021), whether human-induced or due to natural factors.

Water is, likewise, essential to growing crops, but agriculture is facing challenges from exponential growth in global demand for water with an annual one percent increase in water withdrawals since the 1990's (Teng and Adriano

2 Agricultural land use in SEA comprises arable land mainly for food crops and land under permanent plantation crops, 52 percent and 36 percent, respectively, of total agricultural land, with the remainder in permanent pastures (see Table 1) (ASEANstats 2022). The five major food crops grown in SEA are rice (paddy), maize, soybean, sugarcane, and cassava, with rice being the largest in arable land use. Oil palm, fruits, rubber, and coconut occupy most of the permanent land use. Although this distinction between arable and "permanent" is an arbitrary one, it is possible that most of the arable land is planted to annual, short-season crops, while the permanent land is grown with plantation crops (e.g., oil palm, rubber) and crops that last several years (e.g., coconuts, fruit trees).

2021). Given sustained high growth rates of SEA economies in the past two decades, their agricultural sector has faced increasing water competition with other economic sectors (mainly industry and energy), partly due to rising population, increasing urbanization, and rising incomes alongside an increase in the number of affluent middle-income class with diverse requirements.

Combined with climate change, the water-related concerns have resulted in pressing challenges, such as (1) water scarcity or the imbalance between supply of freshwater and the competing demand for water, and (2) water shortage arising from inadequate rainfall patterns. Thailand and Indonesia, which are upper middle-income countries, are already experiencing medium to high levels of water stress, while the lower middle-income economies of Cambodia, Lao PDR, and Myanmar are within the low baseline water stress. No SE Asian country so far falls under the most-stressed water levels.

Changing Demographics and Evolving Consumer Demand

Amid the global push for industrialization in the post WWII era in search of rapid economic development and for improvements in income per capita, countries started to see agriculture's contribution to GDP decline several decades ago (FAO 2021b). SE Asian agricultural employment has also declined as economies develop and generate more of their GDP from non-agriculture activities (see Table 1), with the Asian Development Bank's (ADB's) 2022 key performance indicators showing that in 2021 agriculture's contribution to GDP ranged from 0 percent for Singapore to 24.3 percent for Cambodia.

On the one hand, agriculture is still an important source of rural employment, comprising as much as 28 to 45 percent of the population in six ASEAN countries. Agricultural commodity trade likewise plays an important role in exports by the agricultural-surplus countries—Indonesia, Malaysia, Thailand, and Myanmar and in the imports (particularly of staples) by the net importers.

However, most countries in the region have experienced rural-to-urban migration given better employment opportunities in the services and manufacturing sectors and access to basic services in the metropolis (Teng and Adriano 2021). This has contributed to a declining number of rural workers—from 66 percent in 1980 to 50 percent in 2010, forecasted to decline further to 45 percent (Desker, Caballero-Anthony, and Teng 2013)—and a demographically aging rural population.

With a rapidly growing population in need of more food supply and a decrease in people in rural areas and workers in the agricultural sector, the region's food availability is at risk unless changes are made in technology, practice, and policies (Teng, Caballero-Anthony, and Montesclaros 2021). Since labor is an important input component of food production, the decline in farming population exacerbates the broadening gap in producing sufficient output to address food demand. This leads to rising SE Asian food prices and the need for more labor-saving technologies, such as mechanization.

There is also growing concern about the maturing age of the farmer population. A rural demographic survey reveals that the average age of farmers in developed economies is within the retiring age range (above 55 years old) (Johr 2012). FAO data shows that the agricultural labor force in Asia, relative to total labor force, has remained relatively stagnant for the past decades with barely marginal increments (refer to Table 1). This further increases the pressure because younger workers are becoming fewer to replenish the maturing farmer population. It is thus critical to promote strategies that make agriculture an attractive career for the younger population.

Changing demographics in ASEAN pose further challenges in growing urban populations, accompanied by an increase in middle class families, which have changed demands for new protein-rich diets. According to ADB (2020), all the ASEAN countries at least doubled their nominal GDPs in 2000–15. Amid rising incomes, food consumption has shifted away from a mainly cereal diet to one that includes more resource-intensive food products, such as meat, dairy, eggs, fruits, and vegetables. Such changes in dietary preferences and increases in food prices are among the factors that led to the expansion of land used to produce such food items that compete with rice as a staple for the majority of the population.

DIGITAL TECHNOLOGIES ADDRESSING CHALLENGES IN AGRICULTURE

In the 20th century, green revolution technologies such as synthetic fertilizer, improved seeds, mechanization, pesticides, water augmentation, and digitalized equipment impacted differentially among countries on the favorable farmlands, like irrigated rice, in contrast to the more marginalized rainfed areas (Teng 2021). The high-yielding varieties of crops were complemented by improvements in production inputs and practices. The rise in crop productivity was largely attributable to the adoption of high-yielding varieties, and increased investment in irrigation and fertilizer. These improvements had important implications for economic and social development in the many SE Asian countries that relied heavily on the agriculture sector, particularly in diminishing poverty and in stimulating economic growth.

This century is seeing a new set of technologies such as digital, biotechnological, and nanotechnological that can potentially change the agricultural landscape significantly. While SE Asian countries with a more developed rural sector such as Malaysia and Thailand will have the capacity to use such advanced technologies, some like Myanmar, Lao PDR, and Cambodia will still have much room to increase their use even of earlier 20th century technologies from the green revolution of the 1960s–90s.

The adoption of novel technologies in the 21st century to improve rural economy is likely to vary according to the stage of development in the rural areas. Technologies on their own are not sufficient to effect change in rural communities if conducive policies and institutional enablers are not present as well (Teng and Montesclaros 2023). At the same time, a suite of technologies has already proven effective during the first green revolution of the 1960s/70s in ASEAN and presents an opportunity to tap to meet new challenges.

Advances in urban farming and agro-technology have been used in small urban city-states and net food-importing countries like Singapore (Teng et al. 2019). These have occurred in response to the major social and economic changes as well as to the prevalence of food supply chains for modern food retail systems such as supermarkets. Therefore, a major challenge facing ASEAN is to ensure that access to the disruptive technologies that will make food security sustainable is equitable. Smallholder farmers' adoption of digital technology will be important for digital agriculture to be a significant development driver.

Relative to other novel technologies in agriculture and despite previous works highlighting their potential, there is general lack of understanding and appreciation of the potential of digital technologies in agriculture. We therefore proceed with our proposed classification of digital technologies in agriculture as a means of describing their relevance to the challenges discussed above.[3]

A Proposed Framework for Understanding and Classifying Digital Technologies

To respond better to the needs of farmers and companies as ultimate adopters, this paper suggests that digital technologies benefit from a simple grouping scheme according to function, application, and, implicitly, solution of problems faced in agri-food systems.

This schema builds on earlier work supported by the Economic Research Institute for ASEAN and East Asia (ERIA) and the ASEAN Secretariat in 2020–21 (Montesclaros, Teng, and Caballero-Anthony 2023). Digital technologies are grouped

3 Appendix 1 provides further context in highlighting some previous efforts in showcasing successful examples, case studies, and analysis on digital technologies (AgFunder 2023; FAO and ITU 2017; 2018; OECD 2019).

according to functions they perform along a common food value chain (treated here as equivalent to supply chain) (Figure 2) focused on addressing three key issue-areas: production, supply chain, and digital finance (including financing of production and supply chain operations and linking to consumers). The applications of these technologies across the supply chain are further elaborated in figures 3–5 below, as some technologies are relevant to more than one of these three key issue areas. For instance, digital payments and agri e-commerce are significant to both finance and production.

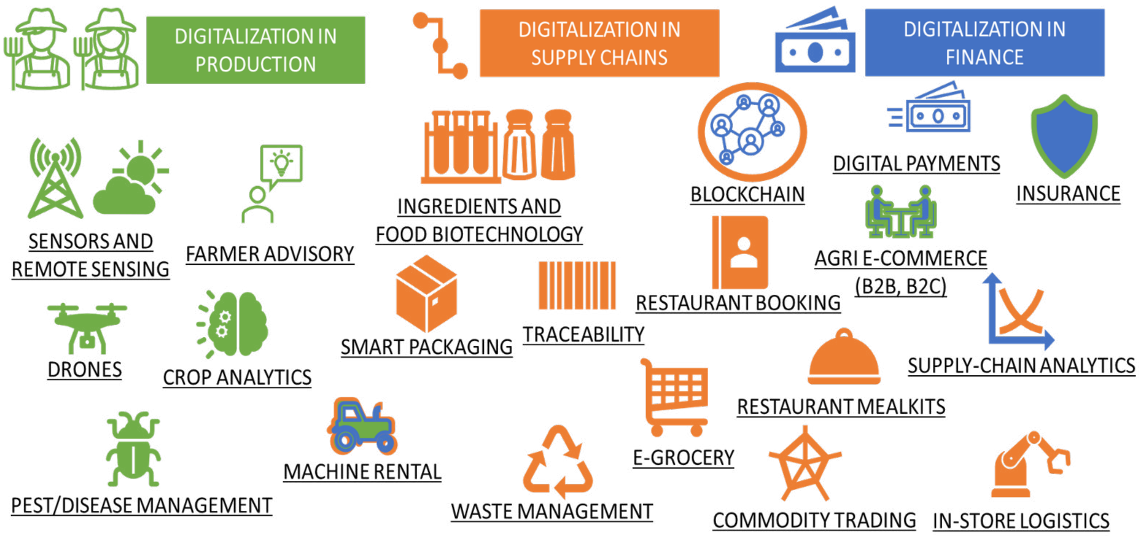
Digital Technologies in Agricultural Production (Agtech)

A significant change is much needed in technology application in narrowing yield gaps (difference between attainable, research yield, and actual farmer's yield) caused by physical, biotic, and management factors. Yet, declines in crop yield growth across Asia's subregions, notably in rice and wheat, have been documented as yield declines in long-term experiments (Dawe et al. 2000) and reduced growth in average yields in farmer's fields (Savary et al. 2022).

Digital technologies offer opportunities to help farmers address farming productivity through "smart farming practices" that include application of the IoT in agriculture (Montesclaros, Babu and Teng, 2019). These start with real-time sensors tracking environmental conditions as well as farmer practices, crop growth, and the onset of droughts, floods, pests, and diseases, including satellites and drones for remote sensing, and in-situ/ground sensors for tracking crop growth. These also allow for developing exact and current estimates and measures of the magnitude and extent of land degradation as empirical evidence on the state of land degradation in SEA is sparse and, when available, are outdated.

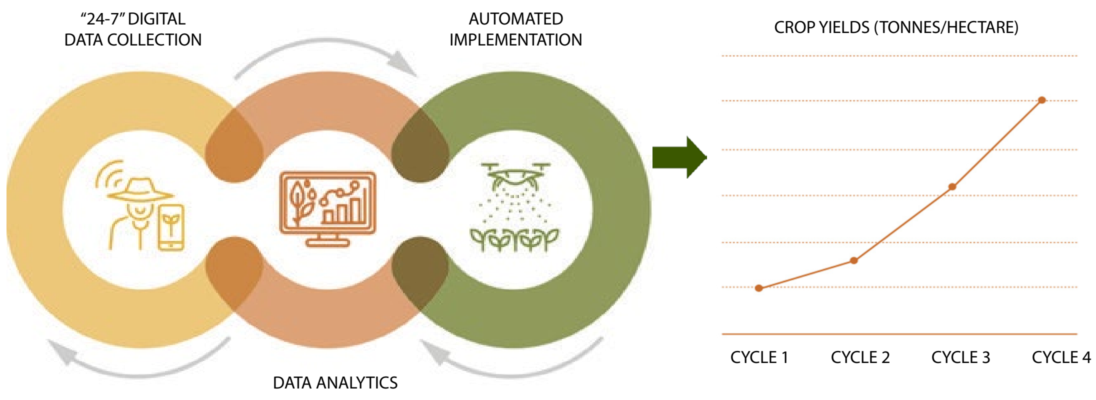
Secondly, crop and weather data analytics and digital farmer advisory services could help farmers plan the optimal cropping and management systems for each farm-field to increase crop yields by narrowing yields gaps and reducing pest losses, coping with climate change effects. Use of farmer advisory services supported by decision-support

Figure 2. Digital technologies by function along a generalized agri-food value chain



Source: Adapted from Montesclaros, Teng, and Caballero-Anthony (2023)

Figure 3. Positive "cycles of growth" within digitally enabled agriculture (Agtech)



Source: Adapted from Montesclaros (2021)

systems software could also help farmers plan the optimal cropping and management systems for each farm-field.[4]

Thirdly, the use of automation (e.g., drones, smart tillers, and weeders) can further allow for targeted and even input application to improve use of inputs (e.g., water, fertilizer, pesticides). Postharvest losses could also be reduced using automated tractors, minimizing labor costs as well as timely harvesting of crops to preserve the quality.

In combination, these three key technologies allow for positive "cycles of growth" or improved productivity and yields over time (Montesclaros 2021) as illustrated in Figure 3. With each succeeding season, more data is collected using sensors that generate data on the responsiveness of crops to fertilizers and other inputs, in turn, feeding to a richer base for crop analytics and improved recommendations to farmers. As these are implemented using automation or hybrid manual/automatic mechanisms, yields can be further increased.

The use of digital technologies to improve agricultural productivity within countries also contributes to increasing the resilience of supply chains against shocks (such as climate impacts), i.e., the capacity and capability to buffer external shocks. This results in increased regional and national productions—relying less on producers from outside the region.

Digital Technologies in Agricultural Supply Chains

The robust trade in the region has been achieved through a mix of public- and private-sector investments sourced intra- and extra-regionally. Following the phased roll-out of the ASEAN Economic Community (AEC) in 2015, there has been increased intra-ASEAN trade arising from the formation of an integrated market, a central goal of the AEC.[5] Also emerging in ASEAN are a significant number of agri-food industry entities, which have in their portfolios activities spanning more than one part of the supply or value chain, and with revenues exceeding USD 1 billion, as exemplified by Olam and Wilmar (Singapore), CP Group (Thailand), and Sime Darby (Malaysia) (Dy et al. 2023).

4 This is exemplified using the Decision Support System for Agrotechnology Transfer (DSSAT) (Gonzalez et al. 2021). While this is common in the Americas and Europe, we have not encountered significant application in SEA. Hence, this problem area is omitted from further discussion.

5 Many have likewise signed on to the Regional Comprehensive Economic Partnership (i.e., RCEP) and the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (i.e., CPTPP).

However, a key challenge is the high degree of food waste across agri-food systems, which happens across all phases from production (agriculture) to postharvest processing, to distribution via supply chains, wholesale markets, and eventually to retail consumers (FAO 2021a). Previous studies have identified multiple "leakages" along the phases. An estimate of as much as half the harvested crop from farmers' fields may be lost or wasted after it leaves the farm and before it reaches the consumer (Rolle 2023).

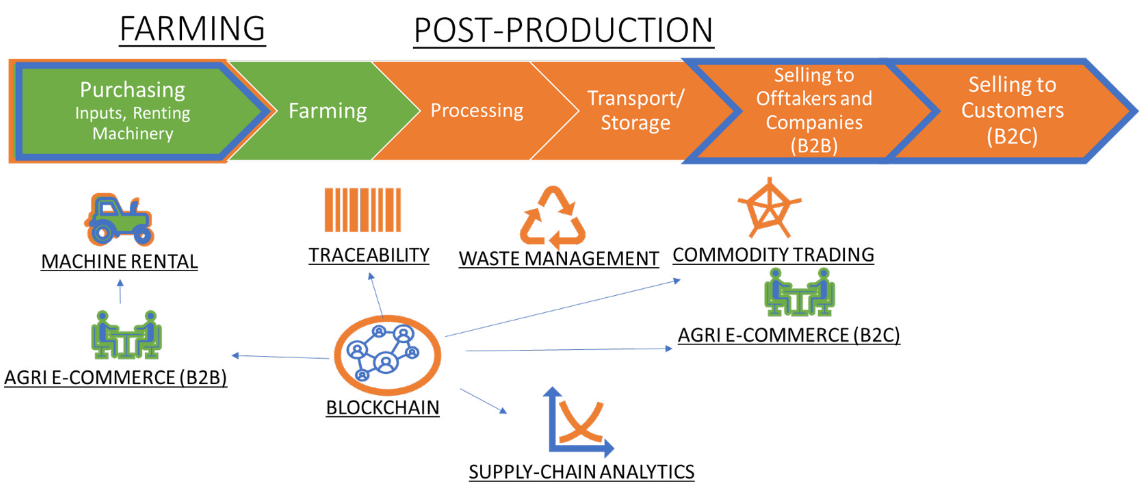
Blockchain technologies allow for e-commerce to help in "shortening" the supply chain, by providing a secure data infrastructure for farmers to market directly to consumers, while at the same time ensuring the safety and quality of food products through traceability technologies. This further contributes to increasing the efficiency of supply chains by reducing the uncertainties faced by farmers in marketing their products, by giving them market information that they can leverage to better tailor their products to the needs of the growing regional population; hence, minimizing food waste. It further allows for streamlining coordination of machine rentals for cooperative enterprises (Figure 4).

Traceability is also of growing importance as it allows farmers to better access export markets. When integrated with farmer advisory services, traceability can serve as an entry point as well for aggregators or "offtakers" to better understand the sourcing of inputs as well as farming practices and identify points of improvement through farmer advisory for more efficient input use. This in turn helps to increase the efficiency of contract farming practices, whereby aggregators loan inputs to farmers and purchase crops at pre-agreed prices.

Technologies for Financial Digitalization (Fintech)

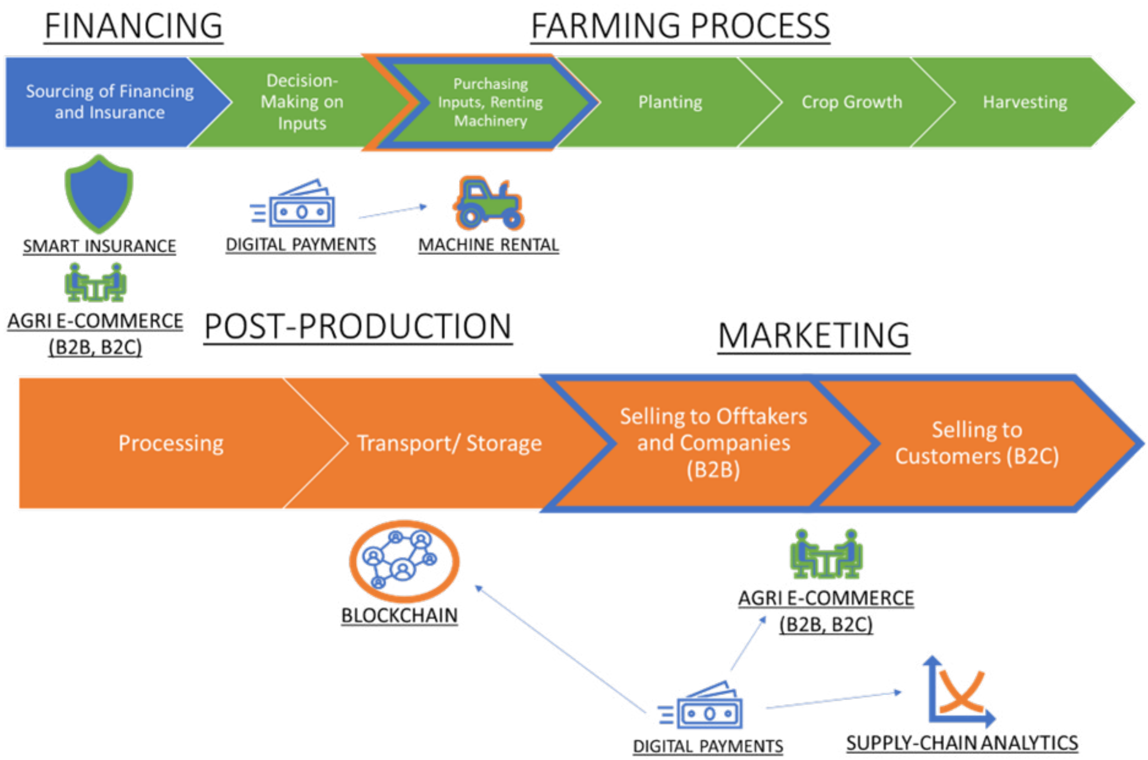
Finally, providing digital finance access to farmers facilitates their integration into the digital economy and allows for a more stable agricultural practice (Figure 5). Fintech can improve farmers' access to financing and transform smallholder farming practices. Greater financial access allows them to utilize better inputs (e.g., fertilizers, seeds, pesticides, organic inputs, as well as crop varieties that are more tolerant of droughts and floods and resistant to pests and diseases), which links back to increased access to and adoption of modern farming technologies.

Figure 4. Centrality of blockchain technologies within supply chain



Source: Snippet of original figure, modified from Montesclaros, Teng, and Caballero-Anthony (2023)

Figure 5. Centrality of digital payments within the supply chain



Source: Snippet of original figure, modified from Montesclaros, Teng, and Caballero-Anthony (2023)

Key to drawing more financing to farmers is integrating digital finance with other digital applications such as e-commerce and traceability. These give private companies a better understanding of farmers' processes and financing requirements, in turn, rationalizing further financial support and enabling crowdfunded applications too. Agri B2B e-commerce likewise allows for disbursement of funding to farmers to support existing contract farming practices. Fintech also enables e-commerce by allowing farmers, traders, and consumers to sell and purchase food products using e-wallets tagged to mobile phone accounts, regardless of whether they have formal bank accounts with established financial institutions. Having mobile financial accounts that can make and receive payments include farmers more into rapidly evolving e-commerce supply chains.

The proposed classification framework was used in facilitating discussions among the ASEAN Sectoral Working Groups (i.e., AWSGs) on crops, fisheries/agriculture and livestock and the ASEAN Technical Working Group on Agricultural Research and Development (i.e., ATWG-ARD). According to these groups, digitalization in agriculture was still seen as a novelty that was beyond the expertise of governments alone. However, it was also generally recognized that digitalization is important and hence was formulated the ASEAN Guidelines on Promoting the Utilization of Digital Technologies for ASEAN Food and Agricultural Sector, produced by the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (i.e., SEARCA) and the ASEAN Secretariat, and informed by the study of Montesclaros, Teng, and Caballero-Anthony (2023). These guidelines were then presented by Professor Hidetoshi Nishimura, then president of ERIA, to the 43rd Meeting of the ASEAN Ministers on Agriculture and Forestry in October 2021, which subsequently endorsed the said guidelines.

FINDINGS FROM ASSESSMENT OF DIGITAL TECHNOLOGY ADOPTION

Based on the proposed classification above, we discuss the adoption of digital technology in each problem area in SEA, except for the pre-season decision-making as no use case was found during the research for this paper. The state of adoption of digital technologies in agriculture was assessed using databases analyzed in 2021 such as the Grow Asia Digital Directory (2021), the AgFunder AgtriFoodTech Report on ASEAN (AgFunder 2020), and the GSMA Digital Agriculture Maps (GSMA 2020a) to account for the provision of digital agriculture services in production, supply chains, and finance. These were further complemented with GSMA's Mobile Connectivity Index (GSMA 2020b) and the World Development Indicators (The World Bank 2022) to account for challenges in ICT infrastructure, as well as the World Bank's Financial Development Index (Demirguc-Kunt et al. 2018) and the International Monetary Fund's Financial Access Survey (IMF 2020) to provide further information on digital financial access (both before and during the COVID-19 pandemic, and in urban and rural areas, pre-pandemic).

Digital Technology Use in Production (Agtech)

The majority of the Agtech applications (i.e., digitalization in production) in ASEAN are focused on crops, although there are initial efforts in applications to the fisheries and aquaculture sector (Table 2). Technical and technological expertise in utilizing novel, relatively expensive technologies, such as drones on food crops, is generally lacking. Application of real-time sensors in agriculture is also limited, owing to poor and unstable internet access, high startup costs, and expenses in maintaining the data infrastructure and in analyzing data. Furthermore, automation is not yet a common practice in agriculture within the region because of budgetary constraints and the lack of farmer training in using automated equipment. There is also no centralized data-sharing framework within the region with data

Table 2. State of digital technology adoption in agricultural production per ASEAN country, in 2020/2021, in number of providers of each type of technology

	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
Digital Production Technologies (AgTech)									
Remote Sensing (GA)	0	1	0	1	1	1	0	1	1
Drones and Imagery (GA)	0	1	0	1	0	0	1	1	1
Drone Analytics (GA)	0	0	0	0	0	1	1	0	0
Food Biotech (AF)	0	0	0	0	0	0	2	1	0
IoT (GA)	0	1	0	0	0	1	0	0	4
Management Farmer (GA)	0	5	0	4	0	2	0	2	3
Advisory Farmer (GA)	4	10	0	2	4	7	0	3	9
Pests and Diseases (GA)	0	1	0	0	0	0	0	0	1
Soil Testing (GA)	0	0	0	0	0	0	0	0	0
Digital Advisory (GSMA)	3–4	5+	0	1	5+	3-4	NA	1	5+
Smart Farming (GSMA)	0	3–4	0	1	1	0	NA	1	2

Source: Adapted from Montesclaros, Teng, and Caballero-Anthony (2023)
Note: GSMA - GSM Association; GA - Grow Asia

geo-tagged at the farm-level, nor within countries (Montesclaros 2023a).

Most digital applications in production among the AMS focus on digital farming advisory services, namely on how to maximize yields with better production practices based on digital information. These leverage crop data analytics, such as machine learning, in optimizing yields or, alternatively, expert advice from agronomists and plant pathologists as in the case of the Rice Doctor application of the International Rice Research Institute (i.e., IRRI). This also provides information on how to engender climate-smart practices within farms with some companies even providing solutions that are linked to weather and remote-sensing or IoT technologies. Cambodia, Indonesia, Malaysia, Myanmar, the Philippines, Brunei, and Vietnam all have more than one company providing this service. Some of these companies are focused purely on farmer advisory, including Crop Base (Malaysia), Greenway, Hub and Htwet Toe (Myanmar), and GREENCoffee (Vietnam).

In SEA, Indonesia has the largest number of companies providing farmer-advisory services, followed by Vietnam and the Philippines. While many companies are providing solely farmer advisory services, most of them offer integrated services, whereby advisory services are linked to other services. Integration within digital production technologies can be observed in the linkage of farmer advisory services to farmer management services. It focuses both on farm technologies and on maximizing farmer revenues and profits as an enterprise. This is applicable in the case of SIPINDO (Indonesia).

In some cases, farmer advisory services are also linked to digitalization in supply chains. These services are linked to traceability solutions in the case of MyCrop (Indonesia); FarmCloud (Indonesia, Cambodia, and Philippines); TaroWorks (Philippines, Cambodia, and Indonesia); and GeoTraceability (Indonesia, Malaysia, and Vietnam). They are also linked to supply chain intelligence in connecting farmers to high-value markets and to those that recognize the value of organic certification, such as in Farmerlink (Philippines) and, beyond ASEAN, SmartRisk (India). Alternatively, these can be linked to digital agriculture trading in the case of Golden Paddy (Myanmar, Vietnam). Moreover, some farmer advisory services are linked to digitalization in financing or fintech applications.

Most ASEAN countries have at least one provider each for either remote sensing, drone technologies, or ground sensors. There is one provider for remote sensing in Indonesia, Malaysia, Myanmar, the Philippines, Thailand, and Vietnam. Similarly, there is one provider for drones and imagery in Indonesia, Malaysia, Singapore, Thailand, and Vietnam. As far as ground sensors and IoT are concerned, there are four providers in Vietnam, and there is one provider each in Indonesia and in the Philippines. However, companies providing drone analytics are only available in Singapore and in the Philippines. Moreover, both sensing and data analytics technologies appear to be less prevalent in the case of Brunei, Cambodia, and Laos although this could also be under-reported.

Some countries have supportive laws and regulations for farmers. For instance, Malaysia has its National Agrofood Policy 2.0 (2021–30) and 12th Malaysia Plan (2021–25), which are focused on transforming the agriculture sector in line with the 4th industrial revolution and Sustainable Development Goals (i.e., SDGs) 2030.[6] However, automation and robotics in agriculture (see Figure 1) are not yet common practice. As in many countries, manual processes are still the norm.

Digital Technology Use in Supply Chains

Digitalization in supply chains in the region is concerned mainly with traceability, i.e., pinpointing the sources of the food products, the ingredients used, and the processes adopted in production. While governments seek to promote traceability, farmers have limited resources to

6 In Sarawak state, there is even a blueprint for a digital economy that includes the agriculture sector (Jugah et al. 2022).

Table 3. State of digital technology adoption in agricultural supply chains per ASEAN country, in 2020/2021, in number of providers of each type of technology

	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
Digital Production Technologies (AgTech)									
B2B e-commerce (AF)	0	2	0	0	0	0	0	0	1
B2C e-commerce (AF)	0	2	0	0	0	0	0	0	0
Supply chain intelligence (GA)	0	6	0	2	1	2	1	2	1
Traceability (AF, GA)	2	12	0	6	1	7	1	5	6
Hire Tractor (GA)	0	0	0	0	1	0	0	0	0
Trading	0	1	0	0	1	0	1	0	1
In-store tech (AF)	0	1	0	0	0	0	6	0	0
E-grocery (AF)	0	1	0	2	0	0	2	0	1
Restaurant booking (AF)	0	0	0	0	0	0	1	0	0
Green packaging materials (AF)	0	0	0	0	0	0	1	0	0
Online restaurant and mealkit (AF)	0	4	0	1	0	0	3	0	0
Digital procurement (GSMA)	3–4	5+	0	3–4	0	3–4	NA	2	5+
Agri e-commerce (GSMA)	2	5+	0	0	0	2	NA	3–4	0

Source: Adapted from Montesclaros, Teng, and Caballero-Anthony (2023)
Note: GSMA - GSM Association; GA - Grow Asia

implement it and financial incentives for them are lacking (Table 3).

The private sector in ASEAN most frequently provides technology on supply chain traceability solutions. Indonesia is leading in providing this technology with approximately 12 companies, followed by the Philippines (seven companies), while Malaysia and Vietnam have six companies each. The most internationalized companies are present in over four ASEAN countries: SimpleAgri (Indonesia, Malaysia, the Philippines, and Thailand) and mFish (Indonesia, Myanmar, Philippines, and Thailand).[7]

A few solutions integrating traceability with digital production can be found in SimpleAgri, which focuses on farmer management tools (Indonesia, Laos, Malaysia, and the Philippines), and RT Analytics (Vietnam).[8] There are also linkages between traceability solutions and IoT solutions (including sensors) in the case of Sat4Rice (Vietnam). Beyond production, further integration can be seen in technologies that link traceability with financing, such as in the case of FarmForce (Indonesia, Thailand, and Vietnam), and with mobile payments such as in the case of AgUnity (Indonesia).

For e-commerce, some countries have their own systems, which are online buying and selling platforms for agri-food products that connect local producers to markets. The Philippines has the electronic Kadiwa or e-Kadiwa (farm produce-on-delivery) system. Also, its AGRIKonek program features a farmer dashboard that enables

7 Some of the companies providing purely traceability services include neoInt (Indonesia, Malaysia, and the Philippines); Blockchain Advisory; Dynamic Discounting; Jupiter Chain (Indonesia, Malaysia, and Vietnam); ScanTrust (Vietnam); FarmERP (the Philippines and Thailand); eService Everywhere (Malaysia and the Philippines); BlueNumber (Myanmar and Indonesia); and Talad (Thailand).

8 We have previously discussed traceability technologies linked with farmer advisory services, so we will not discuss these further here.

agripreneurs to manage their inventory and control production cost online.

Singapore, likewise, has private sector-led e-commerce, which is provided by companies with no direct intervention by the government. E-commerce among farmers is currently being provided by private companies like Redmart, which delivers food to consumers. In Malaysia, the government has its own e-commerce platforms, such as the Agro-Bazaar Online platform.

However, for the most part, digital technologies in agricultural supply chains are still in nascent stages of adoption. Even as Indonesia is potentially the largest market for e-commerce in SEA, with a population of more than 270 million people, most of its e-commerce activity is still concentrated in non-agricultural products. While Singapore is leading in terms of e-commerce adoption owing to its high level of development, its less than six million population makes up a small share of the ASEAN market of more than 650 million individuals.

AMS participants shared farmers' use of social media applications for marketing their products, although the imperative remains to expand rural internet access. Finally, in digital procurement of inputs, most countries have basic banking and electronic payment systems in place. Some are also providing soft loans to support farmers in input procurement.

Digital Financial Services (Fintech)

ASEAN has over 100 million smallholder farmers, many of whom have inadequate access to financial services. It would therefore seem that improving adoption of digital financing and its technology would help address this problem (Table 4).

Indonesia has the greatest number of companies providing digital financial services, followed by the Philippines, then Thailand and Vietnam. There has also been growth in fintech use during the COVID-19 pandemic in terms of the number of mobile and internet-based transactions, registered mobile accounts, and transactions relative to the population (i.e., transactions per 1,000 adults). The Philippines is among the pioneers in providing digital financial services to the "bottom of the pyramid" (Prahalad and Hart 2002). This came in the form of two initiatives: the central bank's Paleng QR, which assigns each farmer or stakeholder a unique QR code to conduct sales and purchases, and the GCash e-wallet developed to assign a credit rating (GScore) for each user (GCash 2023). The latter has empowered even the poorest farmer to have a credit rating and the GScore has become an industry de facto standard.

Across digital financial technologies, Indonesia is the strongest with approximately seven companies providing this service, followed by the

Table 4. State of digital technology adoption in digital finance per ASEAN country, in 2020/2021, in number of providers of each type of technology

	Cambodia	Indonesia	Laos	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
Digital Supply Chain Technologies (Blockchain)									
Financing (GA)	2	8	0	3	1	5	0	4	4
Digital finance (GSMA)	2	3–4	0	2	5+	5+	NA	2	2
Insurance (GA)	0	1	0	0	2	1	0	0	0
Mobile payments (GA)	0	1	0	0	0	0	0	0	0

Source: Adapted from Montesclaros, Teng, and Caballero-Anthony (2023)
Note: GSMA - GSM Association; GA - Grow Asia

Table 5. Key constraints in scaling digital technology adoption in ASEAN and policy opportunities

Key Costraints	Policy Actions
Smallholder financing: Capitalization challenges of smallholder farmers	1. Conduct crop-market-area value chain assessments and private sector consultations 2. Develop a consortium of private and international financing providers for supporting digital transformation
Smallholder farmer attitudes: Cultural and trust barriers in promoting digital advisory services	3. Encourage the AMS to explore combined online-offline modes of delivering agricultural extension services
Trade and e-commerce: Sporadic and insufficient scaling up of e- commerce in agriculture	4. Develop an ASEAN platform for cross-boundary e-commerce in agriculture 5. Integrate digital traceability requirements into ASEAN food safety regulatory framework (AFSRF) 6. Develop targeted information campaigns on the importance of e-commerce services in the agricultural sector to target consumers and farmers
Information and communications technologies and intellectual property: Lack of inter-operability across digital applications	7. Develop a harmonized standard for data applications in agriculture and an ASEAN platform for data applications in agriculture 8. Integrate data and intellectual property protection and security in agriculture within the ASEAN framework agreement on intellectual property cooperation
Challenges in enabling infrastructure for digitalization	9. Encourage country-level plans to map out "first-to-last" mile travel routes and digital connectivity to enable e-commerce

Source: Modified from Montesclaros, Teng, and Caballero-Anthony (2023)

Philippines with four companies, and Thailand and Vietnam with three companies each. The company iAPPS is the most internationalized with operations in Indonesia, Myanmar, the Philippines, and Thailand. This is followed by Smartfarms Network Pte. Ltd., which has operations in two countries on the trial stage.

Many ASEAN countries still have low e-commerce penetration. As of 2017, only Singapore had high e-commerce penetration at 48 percent, which is greater than China's at 45 percent, followed by Malaysia at 34 percent. These divides have important implications on the agriculture sector where farmers are aging (Rigg et al. 2020) and their average educational level is lower than those in services and industrial sectors. This is brought about by rapid urbanization and job migration to industrial and services sectors, which require higher educational attainment.

KEY ISSUES AND POLICY OPPORTUNITIES IN UPSCALING ADOPTION OF DIGITAL AGRICULTURE

Most of the region's farmers and producers are smallholders on arable land.[9] Five macrolevel issues influencing smallholder farmers' use of digital technologies in SEA were identified in a seminal study conducted by the S. Rajaratnam School of International Studies, Nanyang Technological University (RSIS NTU), with ERIA and the ASEAN Secretariat (Montesclaros, Teng, and Caballero-Anthony, 2023). Alongside these, nine possible policy actions that could help accelerate the contribution of digitalization to agricultural development in SEA were also suggested (Table 5) and further elaborated in Montesclaros, Teng, and Caballero-Anthony (2023). However, it is anticipated that different AMS will experience

9 While there are also significant large-scale plantations—in permanent agriculture land use—producing palm oil and rubber, our focus is on challenges faced by the smallholder farmers who are dominant in the region.

different constraints among their smallholder farmers in adopting digital agriculture. Some of the key challenges directly relevant to farmers are summarized in the succeeding discussions.

Unique Challenges of Smallholder Farmers

An estimated 100 million smallholder farmers in the ASEAN region (Mikolajczyk et al. 2021), each farming less than 2 ha, remain an important part of the food-producing landscape. While large-scale commercialized farming sustains demand for food through higher output and greater productivity, criticisms persist on its ability to alleviate poverty and threats to environmental sustainability (Teng and Adriano 2021).

The inefficiencies in food agriculture are exacerbated by the uneven access to technology on the part of smallholder farmers. Additionally, every smallholder farmer may be considered as having his/her own farm management style, which collectively makes it challenging to improve agriculture in toto (Teng 2021). A key barrier, however, is that a "trust gap" exists, wherein "farmers perceive that private companies offer such services to market their related products rather than to transfer and build farmers' knowledge" as argued earlier by Montesclaros (2023b), drawing insights from previous studies by UNESCAP (2016) and Grow Asia (Voutier 2019). Thus, the AMS would benefit from combined online-offline modes of delivering agricultural extension services in upscaling digital technology adoption in agriculture.

Smallholder's Capitalization Challenges

In their use of digital technologies for crop production, farmers must have the financial capability to invest. A common problem in introducing a new technology is demonstrating the cost-benefit in using such a technology, such as increased yield, lowered risk, or increased efficiency of input use. As most smallholders remain at the subsistence level and are poorly capitalized, governments will have to consider programs to support the introduction and adoption of digital technologies.

Farm sizes have important implications for food production because relatively large, consolidated farms can be more efficient and productive by optimizing mechanization and using modern technologies. These trends and patterns point to the unequivocal importance to identify smallholders as an important stakeholder group in agriculture in the ASEAN agri-food sector and to develop approaches that focus on them. Challenges in land reform abound and can prevent farmers from using land as collateral to obtain financing (Montesclaros 2023b; De Soto 2002). ASEAN policymakers in collaboration would, thus, do well to assess the potential scalability and investment worthiness of digital technology products across specific country/area and commodity contexts. Private sector groups could also be organized into a consortium of private and international financing providers for supporting digital transformation to help vet such assessment.

Quality of Farming Output for Trade and E-Commerce

Agri-food supply chains amplify the inefficiencies in the production stage through the many post-farm processes that involve multiple stakeholders. Smallholders, whether in the crop, livestock, or fisheries sectors, are often unable to meet the quality, safety, uniformity, and standards demanded at the higher end of the market. They do not have adequate access to technology, inputs, and financial services required to produce high-quality products demanded by consumers and supplied by new market outlets like supermarkets.

Additionally, because of economies of scale in production and processing, smallholders cannot compete with industrial production systems in the use of machineries that augment labor in harvesting crops in a timely manner. This provides a strong argument for ASEAN to consider a stronger push toward inclusive agribusiness approaches to sustain growth in the agriculture sector so that smallholders can play a bigger role in food supply chains, especially in times of crisis (Teng and Oliveros 2017).

The rapid transformation of supply chains has obvious implications for food security, particularly for the millions of smallholders in the region who are themselves food insecure. While this transformation has led to higher quality, safer, and cheaper produce for urban consumers, market participation by smallholders is lower (Minten and Reardon 2008). Amid the rising importance of sustainably and ethically produced food within export markets, it is therefore critical to integrate digital traceability requirements into the AFSRF, and to develop targeted information campaigns on the importance of e-commerce services in the agriculture sector to target consumers and farmers.

Increased participation of smallholder farmers into modern supply chains is likewise an issue common to most SE Asian countries (Teng and Oliveros 2017) independent of the state of development of digitalized supply chains. An ASEAN platform for cross-boundary e-commerce in agriculture could further be developed as a spur for farmers to take up such standards, by allowing them greater direct access to export markets.

Connectivity Infrastructure and Interoperability of Applications

While the constraints raised above generally apply to the entire digitalization challenge, specific issues are faced as well in pre-season planning for crop production. For example, digital pre-season planning requires that farmers have the computer equipment and necessary connections to acquire planning software and the know-how to use them. Decision guides like DSSAT also require the aptitude in using computers. Yet among the smallholder farmers in SEA, most do not own a computer or have any internet connections. But this is one aspect where the presence of "agropreneurs" (Ra, Ahmed, and Teng 2019) may be able to address the deficit. On the side of regulators and governments, they could also encourage country-level plans to map out first-to-last mile travel routes and digital connectivity to enable e-commerce by addressing "dark spots" where connectivity is lacking.

Another constraint is the lack of interoperability of existing applications. In other words, applications cannot directly converse with one another, which further raises the costs for smallholder farmers who need to pay twice for accessing weather advisory services and again for converting such advisory into crop advisory services. This in turn could "lock" farmers into their existing service providers, thus preventing an open and competitive environment for such services.

While the lack of interoperability is understandable as the use of digital technologies is still rather nascent, addressing this challenge will be critical in upscaling the adoption of digital technologies in the long-term to boost regional agriculture and food security. A potential solution lies in developing a harmonized standard for data applications in agriculture, which companies can comply with. This should allow their applications to interface with one another within an ASEAN platform for data applications in agriculture. To enable collaboration across companies and participation in such standard platforms, ASEAN policymakers could also integrate data and intellectual property protection and security in agriculture within the ASEAN Framework Agreement on Intellectual Property Cooperation.

CONCLUSION

Agriculture, whether for food or industrial purposes, remains an integral and prominent part of the ASEAN economy. And despite trends of increasing urbanization and decreasing contribution of agriculture to national GDP, agriculture remains an important activity that provides livelihoods to significant parts of the rural populations in most of the AMS. ASEAN's overall productivity and production in food security items like rice, vegetable oil, and fish suggest that these need to be maintained to assure sustainable food security.

Yet, many challenges still confront agri-food systems in SEA. These challenges show specific problem areas that lend themselves to potential digital applications. While there is no universally accepted classification scheme for digital technologies, it is nevertheless possible to propose how specific digital technologies may contribute to solving certain problems arising from the challenges facing agriculture. Although agriculture remains the least-invested sector for digitalization, there is evidence that investment and adoption of digital technologies in agriculture, especially crop agriculture, are growing in SEA, building on some early successes such as in the use of drones and farm advisories.

Our analysis shows that the adoption of digital technologies as tools to improve agriculture and contribute to agricultural development is in a nascent stage. While there are areas of popular use, such as with drones for mapping crop areas, overall, there is little impact so far of the more sophisticated digital technologies like IoT, data analytics, artificial intelligence, and virtual reality.

At a political level, the ASEAN ministers of agriculture, in endorsing the ASEAN Guidelines on Promoting the Utilization of Digital Technologies for ASEAN Food and Agricultural Sector, have sent a strong message that digital agriculture must be an integral part of the vision and strategic plan for the ASEAN Cooperation in Food, Agriculture and Forestry (2016–25), considered the ASEAN blueprint for agricultural development. Application of digital technologies in ASEAN agriculture and agri-based industries and services is inevitable, and it is imperative that deliberate measures be taken by the public sector (via enabling policies and supporting public investments) and the private sector (through further development and wider dissemination of appropriate digital tools and applications) to enable rural communities in the region to reap its benefits.

REFERENCES

ADB (Asian Development Bank). 2020. *Key Indicators for Asia and the Pacific 2020.* Manila: Asian Development Bank. http://dx.doi.org/10.22617/FLS200250-3

———. 2022. *Key Indicators for Asia and the Pacific 2022.* Manila: Asian Development Bank. http://dx.doi.org/10.22617/FLS220346-3

AgFunder. 2020. ASEAN 2020 *AgriFoodTech Investment Report.* Accessed on 17 September 2021. https://agfunder.com/research/asean-2020-agrifoodtech-investment-report/

———. 2023. *AgFunder Global AgriFoodTech Investment Report 2023.* https://agfunder.com/research/agfunder-global-agrifoodtech-investment-report-2023/

ASEANstats. 2022. *ASEAN Statistical Yearbook 2022.* Accessed on 1 October 2023. https://www.aseanstats.org/publication/asyb2022/

Dawe, D., A. Dobermann, P. Moya, et al. 2000. "How Widespread are Yield Declines in Long-Term Rice Experiments in Asia?" *Field Crops Research* 66(2): 175–193. https://doi.org/10.1016/S0378-4290(00)00075-7

Demirguc-Kunt, A., L. Klapper, D. Singer, S. Ansar, and J. Hess. 2018. *Global Findex Database 2017: Measuring Financial Inclusion and the Fintech Revolution.* Washington, DC: World Bank. http://hdl.handle.net/10986/29510

Desker, B., M. Caballero-Anthony, and P.S.Teng. 2013. "Thought/Issues Paper on ASEAN Food Security: Towards a More Comprehensive Framework." *ERIA (Economic Research Institute for ASEAN and East Asia) Discussion Paper Series,* ERIA-DP-2013-20.

De Soto, H., and H.P. Diaz. 2002. The Mystery of Capital: Why Capitalism Triumphs in the West and Fails Everywhere Else. *Canadian Journal of Latin American & Caribbean Studies* 27(53):172–174.

Dy, R.T., S.U. Reyes, M.A. Dacul, D.R. Macabasco, and J.K.L. Orzales. 2023. "The Dynamics of Food Production and Trade to Achieve Food Security." In P.Teng, ed., *Food Security Issues in Asia.* In Press. Singapore: World Scientific Publishing Company. https://doi.org/10.1142/13469

Economist Impact. 2022. *Global Food Security Index 2022*. Accessed 15 May 2023. https://impact.economist.com/sustainability/project/food-security-index/

FAO (Food and Agriculture Organization of the United Nations). 2021a. *The State of Food and Agriculture 2021: Making Agrifood Systems More Resilient to Shocks and Stresses.* Rome: FAO. https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1457191/

———. 2021b. *Agricultural Transformation in Asia: Policy and Institutional Experiences.* Bangkok: FAO. https://doi.org/10.4060/cb4946en

———. 2022. *The State of Food and Agriculture 2022*. https://www.fao.org/3/cb9479en/online/sofa-2022/digital-revolution-agricultural-practices.html

FAO and ITU (Food and Agriculture Organization of the United Nations, and International Telecommunication Union). 2017. *E-Agriculture in Action*. Rome: FAO. https://www.fao.org/3/i6972e/i6972e.pdf

———. 2018. E-Agriculture in Action: Drones for Agriculture. Rome: FAO. https://www.fao.org/3/I8494EN/i8494en.pdf

González, O.R., R.F. Bacallao, N.H. Cordova, et al. 2021. "Simulation of Management Strategies from the DSSAT Model to Increase the Yields of a Corn Cultivar." *Cuban Journal of Agricultural Science* 55(2): e08.

Grassini, P., K.M. Eskridge, and K.G. Cassman. 2013. "Distinguishing Between Yield Advances and Yield Plateaus in Historical Crop Production Trends." *Nature Communications* 4: 2918. https://doi.org/10.1038/ncomms3918

Grow Asia. 2021. "Grow Asia Digital Directory: Digital Solutions for Smallholder Value Chains in ASEAN." Accessed on 17 September 2021. https://directory.growasia.org/

GCash. "GScore." *GCash Help Center.* Accessed on 1 December 2023. https://help.gcash.com/hc/en-us/articles/360017566894-GScore

GSMA. 2020a. *Digital Agriculture Maps: 2020 State of the Sector in Low and Middle-Income Countries.* Accessed on 17 September 2021. https://www.gsma.com/mobilefordevelopment/resources/digital-agriculture-maps/

———. 2020b. "GSMA Mobile Connectivity Index Database 2019." Accessed on 17 September 2021. https://www.mobileconnectivityindex.com/

IMF (International Monetary Fund). 2020. "Financial Access Survey (FAS)." *IMF Data Access to Macroeconomic & Financial Data.* Accessed on 17 September 2021. https://data.imf.org/?sk=E5DCAB7E-A5CA-4892-A6EA-598B5463A34C

Johr, H. 2012. "Where are the Future Farmers to Grow our Food?" *International Food and Agribusiness Management Review* 15 (Special Issue A). https://www.ifama.org/resources/Documents/v15ia/Johr.pdf

Jugah, I., S.Y. Chai, N.A. Yusuf, O. Alfred, and A. Sawai. 2022. "Public Readiness and Acceptance Towards Implementation of Sarawak Digital Economy: A Case Study in Kuching, Sarawak." *Journal of Administrative Science* 19(2):109–118. https://jas.uitm.edu.my/images/2022_DEC/6.pdf

Marie, A. 2022. "Addressing the Digital Divide for Smallholder Farmers." 17 May 2022. *Harvard Advanced Leadership Initiative: Social Impact Review.* https://www.sir.advancedleadership.harvard.edu/articles/addressing-digital-divide-for-smallholder-farmers

Mikolajczyk, S., F. Mikulcak, A. Thompson, and I. Long. 2021. *Unlocking Smallholder Finance for Sustainable Agriculture in Southeast Asia.* Germany: Climate Focus and Worl Wide Fund (WWF). https://sustainablefinanceasia.org/wp-content/uploads/2021/03/WWF-2021-Unlocking-Smallholder-Finance-for-Sustainable-Agriculture.pdf

Min, S., H. Waibel, and J. Huang. 2017. "Smallholder Participation in Land Rental Market in a Mountainous Region of Southern China: Impact of Population Aging, Land Tenure Security and Ethnicity." *Land Use Policy* 68(C): 625–637.

Minten, B., and T. Reardon. 2008. "Food Prices, Quality, and Qualitiy's Pricing in Supermarkets versus Traditional Markets in Developing Countries." *Review of Agricultural Economics* 30(3): 480–490.

Montesclaros, J.M.L. 2020. "Southeast Asia's Food Security: Inflection Point?" In M. Caballero-Anthony, L. Gong, eds., *Non-Traditional Security Issues in ASEAN: Agendas for Action.* Singapore: ISEAS Publishing. https://doi.org/10.1355/9789814881098-004

———. 2021. "The "Internet of Things" in Agriculture: Pitfalls and Opportunities." *The Head Foundation Digest,* December 2021. https://headfoundation.org/wp-content/uploads/2021/12/THINK-9_Tomorrows_Technology_Today.pdf

———. 2023a. "Empowering Digitalisation in ASEAN Agriculture: Lessons from EU Regional Platforms for Geospatial Technologies." *RSIS Policy Report,* July 2023. Singapore: Nanyang Technological University.

———. 2023b. "Institutions and Agricultural Transformation: A Study of Induced Innovation in the Philippine Rice Sector." Unpublished PhD Dissertation. Singapore: Nanyang Technological University.

Montesclaros, J.M.L., and P.S. Teng. 2021. "Agriculture and Food Security in Asia." In J.M. Pulhin, M. Inoue, and R. Shaw, eds., *Climate Change, Disaster Risks, and Human Security: Asian Experience and Perspectives.* 137–168. DOI:10.1007/978-981-15-8852-5_7

Montesclaros, J.M.L., S.C. Babu, and P.S. Teng . 2019. "IoT-Enabled Farms and Climate-Adaptive Agriculture Technologies: Investment Lessons from Singapore." *IFPRI Discussion Paper* 1805. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/p15738coll2.133079

Montesclaros, J.M.L., P.S. Teng, and M. Caballero-Anthony. 2023. *Digital Technology Utilization in the Agriculture Sector for Enhancing Food Supply Chain Resilience in ASEAN: Current Status and Potential Solutions: RSIS Project Report June 2023.* Singapore: S. Rajaratnam School of International Studies, Nanyang Technological University; and Economic Research Institute for ASEAN and East Asia. https://www.rsis.edu.sg/wp-content/uploads/2023/06/Project-Report-ASEAN-Digitalisation-Status-and-Solutions_RSIS_ERIA-June2023.pdf

OECD (Organisation for Economic Co-operation and Development). 2019. *Digital Opportunities for Better Agricultural Policies.* Paris: OECD Publishing. https://doi.org/10.1787/571a0812-en

Prahalad, C.K. and S.L. Hart. 2002. "The Fortune at the Bottom of the Pyramid." 10 January 2002. Strategy+Business. https://www.strategy-business.com/article/11518

Ra, S., M. Ahmed, and P.S. Teng. 2019. "Creating High-Tech 'Agropreneurs' Through Education and Skills Development." I*nternational Journal of Training Research* 17: 41–53. https://doi.org/10.1080/14480220.2019.1629736

Reardon, T., C.P. Timmer, C.B. Barrett, and J. Berdegué. 2003. "The Rise of Supermarkets in Africa, Asia, and Latin America." *American Journal of Agricultural Economics* 85(5): 1140–1146.

Rigg, J., M. Phongsiri, B. Promphakping, A. Salamanca, and M. Sripun. 2020. "Who Will Tend the Farm? Interrogating the Ageing Asian Farmer." *The Journal of Peasant Studies* 47(2): 306–325. https://doi.org/10.1080/03066150.2019.1572605

Rolle, R. 2023. "Reducing Food Loss and Waste in Food Systems." In P. Teng, ed., *Food Security Issues in Asia.* In Press. Singapore: World Scientific Publishing Company.

Savary, S., L. Willocquet, N. Castilla, et al. 2022. "Whither Rice Health in the Lowlands of Asia: Shifts in Production Situations, Injury profiles, and Yields." *Plant Pathology* 71(1): 55–85. DOI: 10.1111/ppa.13490

Schwab, K. 2017. *The Fourth Industrial Revolution.* Switzerland: World Economic Forum.

Streinz, Thomas. 2021. "The Evolution of European Data Law." In P. Craig and G. de Búrca, eds., *The Evolution of EU Law, OUP, 3rd Edition.* 902–936. http://dx.doi.org/10.2139/ssrn.3762971

Teng, P. 2017. "Knowledge Intensive Agriculture: The New Disruptor in World Food?" *RSIS Commentary* 124. Singapore: S. Rajaratnam School of International Studies (RSIS).

———. 2021. "Industry Note: New Disruptive Technologies and Mindsets for Asian Agriculture in the 21st Century." *Int. J. Agriculture Innovation, Technology and Globalisation* 2(2): 186–191.

Teng, P., and L.S. Adriano. 2021. "Rural Transformation of Southeast Asia Agriculture and Natural Resource Sectors: An Insight Paper." Unpublished report submitted to the Asian Development Bank (ADB), March 2021. Manila: ADB.

Teng, P., and J.M.L. Montesclaros. 2023. "Agricultural Transformation for Small (Island and Developing) States." *Asian Journal of Agriculture and Development* 20(1): 13–30. https://doi.org/10.37801/ajad2023.20.1.2

Teng, P., and J.A.P. Oliveros. 2017. "The Enabling Environment for Inclusive Agribusiness in Southeast Asia." *Asian Journal of Agriculture and Development* 13(2): 1–30. https://ajad.searca.org/article?p=688

Teng, P.S., M. Caballero-Anthony, and J.M.L. Montesclaros. 2021. "Chapter Four: ASEAN Responses to COVID-19 for Assuring Food Security." *Advances in Food Security and Sustainability* Vol. 6: 84–116. https://doi.org/10.1016/bs.af2s.2021.07.001

Teng, P., J.M.L. Montesclaros, R. Hulme, and A. Powell. 2019. "The Evolving Singapore Agrifood Ecosystem." *NTS Insight* no. IN19-03, August 2019. Singapore: Centre for Non-Traditional Security Studies, S. Rajaratnam School of International Studies.

Teng, P.S., M. Caballero-Anthony, G. Tian, and JA. Lassa. 2015. "Impact of Climate Change on Food Production: Options for Importing Countries." *RSIS Policy Brief*, May 2015. Singapore: S. Rajaratnam School of International Studies (RSIS). https://www.rsis.edu.sg/rsis-publication/nts/impact-of-climate-change-on-food-production-options-for-importing-countries/

UNESCAP (Economic and Social Commission for Asia and the Pacific). 2016. *Assessment of Stakeholder Interventions for Sustainable Agriculture in Myanmar's Dry Zone: Case Study.* Indonesia: Centre for Alleviation of Poverty through Sustainable Agriculture (CAPSA-ESCAP). https://repository.unescap.org/bitstream/handle/20.500.12870/4269/ESCAP-2016-WP-Assessment-stakeholder-interventions.pdf?sequence=1&isAllowed=y

Voutier, P. 2019. *Driving AgriTech Adoption: Insights from Southeast Asia's Farmers.* Singapore: Grow Asia PartnershipLtd. http://exchange.growasia.org/system/files/Driving%20AgriTech%20Adoption%20-%20Insights%20from%20Southeast%20Asia%27s%20Farmers.pdf

The World Bank. 2022. *DataBank: World Development Indicators.* Accessed on 26 January 2022. https://databank.worldbank.org/source/world-development-indicators

Yuan, S., A.M. Stuart, A.G., Laborte, et al. 2022. "Southeast Asia Must Narrow Down the Yield Gap to Continue to be a Major Rice Bowl." *Nature Food* 3: 217–226. https://www.nature.com/articles/s43016-022-00477-z

Zhao, J., A. Li, X. Jin, and L. Pan. 2020. "Technologies in Individual Animal Identification and Meat Products Traceability." *Biotechnology & Biotechnological Equipment* 34(1): 48–57. https://doi.org/10.1080/13102818.2019.1711185

APPENDIX

Lack of Common Framework for Classifying and Understanding Digital Technologies

A key challenge today is the lack of a generally accepted classification or taxonomy of digital technologies for agriculture. Multiple international organizations have proposed their own classifications based on perceptions of functional capabilities or applications. FAO's co-publication with the International Telecommunication Union focusing on e-agriculture (FAO and ITU 2017) identified specific use cases:

1. Precision farming (sensor data, imaging with real-time data analytics to improve farm productivity through mapping spatial variability in the field)
2. Soil health scans (monitoring crop health, assisting in planning irrigation schedules, applying fertilizers, estimating yield data, and weather analysis)
3. Precision variable rate application (liquid pesticides, fertilizers, and herbicides)
4. Normalized difference vegetation index (NDVI) maps (differentiate soil from grass or forest, detect plants under stress, and assess crop stages)
5. Infrared, multispectral, and hyperspectral sensors (analyze crop health and soil conditions)
6. Crop health assessment/monitoring: NDVI + crop-water stress index (CWSI) and the canopy-chlorophyll content index (CCCI)
7. Computer-aided insurance claims forensics (to compute losses)
8. Farm management (drones, sensors, and farm automation and optimization)
9. High generation ortho mosaics (satellite images for converting multispectral images into accurate reflectance and index maps)
10. Sensors (tracking crop growth stages, weeds, compaction, storm damage)

However, FAO and ITU (2017) did not attempt at the time to develop a general classification of such technologies.[10] A succeeding publication that attempted a more comprehensive classification is that of the OECD (2019), which defined five key groupings:

(1) data collection technologies
(2) data analysis technologies
(3) data storage technologies
(4) data management technologies
(5) data transfer and sharing technologies (including Digital communications; trading, payment, and service delivery platforms)

Each of these technologies is further classified into subgroups. For data collection technologies, further technologies include: (1.1) remote sensing, (1.2) in situ sensing, (1.3) crowdsourcing data collection, (1.4) online surveys / censuses, and (1.5) financial / market data collection. Further details are shown in Appendix Table 1.

While the OECD's grouping of technologies appears functional, it is too detailed and focuses mostly on different uses and management of data.[11] As such, while comprehensive, the OECD's grouping is not suited to how farmers and companies will ultimately use the data. An alternative approach may be more suited to ASEAN, given that digitalization in agriculture is a new theme sparked by the 4th industrial revolution in the past decade of 2010–2020 (Schwab 2017).

A potential alternative to the OECD's classification is that of AgFunder's, which is more application focused. In the AgFunder 2023 report, agricultural technologies are classified according to supply chain segment, covering upstream and downstream.[12] The classification benefits from being application-based with a broader grasp, including non-digital technologies (e.g., Ag biotechnology, bioenergy, and biomaterials). Nonetheless, it is not immediately fit for purpose within ASEAN being rather technical in nature and potentially more suited to investors who tend to perceive such technologies as "upstream" and "downstream." The authors thus believe that a more hybridized functional-application approach would be useful.

Many other organizations have pointed to the significance of digital technologies in agriculture, including FAO (2022) with a briefing paper on such technologies. Another way of framing crop technologies can be Grow Asia's that look into: (1) drones and imagery, (2) farm management, (3) farmer advisory, (4) internet of things (IoT), (5) management of pests and diseases, (6) remote sensing, and (7) soil testing for crop production.[13]

10 FAO and ITU (2018) likewise presented case-studies of drone applications in agriculture, without attempting a general classification.

11 OECD's approach likely stems from a tradition within the EU, of which most OECD countries are also members, surrounding data protection across its member states since the 1990s. This culminated in the EU-wide General Data Protection Regulation in 2016 (Streinz 2021).

12 AgFunder was among the first organizations to track the steady growth of agricultural technology investments globally since 2012. Upstream technologies include innovative food, novel farming systems, bioenergy and biomaterials, Ag biotechnology, farm management software, sensing, and IoT, Ag marketplaces and fintech, and farm robotics, mechanization, and equipment. Downstream technologies include in-store retail and restaurant tech, eGrocer, online restaurants and marketplaces, home and cooking, and cloud retail infrastructure.

13 Furthermore, scholarly works on the importance of digital technologies in supply chains have identified (1) blockchain technologies that facilitate market transactions within agribusiness marketplaces, including commodities trading platforms, online input procurement, and equipment leasing; and (2) food safety and traceability technologies include DNA fingerprinting (for genetic traceability) and stable isotope ratios fingerprinting (for verifying point of origin of meat products); mineral element fingerprinting (for ascertaining traces of metals and chemicals, as well as determining the point of origin); and organic component fingerprinting (for ascertaining the presence of components like protein, fatty acids, etc., and further authentication of geographic origin of plants and animals) (Zhao et al. 2020).

Appendix Table 1. Technology classifications by OECD

Technology Purpose	Category	Subcategory
1. Data collection technologies	1.1. Remote sensing	Satellite-mounted data acquisition / monitoring systems
		UAV / drone-mounted data acquisition / monitoring systems
		Manned aircraft data acquisition / monitoring systems
	1.2. In situ sensing	Water quantity meters
		Water quality sensors, air quality sensors
		In situ meteorological sensors
		In situ soil monitors
		In situ biodiversity, invasive species, or pest monitors
		Crop monitors
		Livestock monitors
		Data from precision agricultural machinery
	1.3. Crowdsourcing data collection	"Serious games" for gathering agri-environmental data
		Citizen science
	1.4. Online surveys / censuses	Data collection portals (e.g., online census)
	1.5. Financial / market data collection	Retail scanner data
		Business software for recording financial or market information (e.g., database entry systems)
2. Data analysis technologies	2.1. GIS-based and sensor-based analytical tools	Digital elevation modelling
		Land use-land cover mapping
		Watershed modelling
		Soil mapping
		Landscape modelling
		Software (programs, apps) for translating sensor and other farm data into actionable information
		Software for automating agricultural machinery which uses sensor or other farm data as input
		Software for measuring and grading agricultural outputs (e.g., carcass grading software)
	2.2. Crowdsourcing data analysis	Crowdsourcing applications for data sorting / labelling
	2.3. Deep learning / AI	Data cleaning algorithms
		Big data analysis algorithms
		Machine learning
		Predictive analytics
3. Data storage technologies	3.1. Secure and accessible data storage	Cloud storage
		Confidential computing
		Virtual data centers
4. Data management technologies	4.1. Data management technologies	Distributed ledger technologies (e.g., blockchain)
		Interoperability programs and apps

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Appendix Table 1 continued

Technology Purpose	Category	Subcategory
5. Data transfer and sharing: digital communications; trading, payment, and service delivery platforms	5.1. Digital communication technologies	Digital data visualization technologies
		Social media
		Web-based video conferencing
		Machine-assisted communication (e.g., chatbots, natural language generation algorithms)
	5.2. Online platforms - property rights, payments, ser vices, and markets	Online property rights and permits registries
		Online trading platforms
		Platform-based crowdfunding for agriculture and agri-ecosystem services
		Online payment platforms (for public programs)
		Service delivery platforms

Source: Table adapted from OECD (2019)