Data-driven advisory services for climate-smart smallholder agriculture

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GSMA Agritech Programme

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The GSMA AgriTech Programme works towards equitable and sustainable food chains that empower farmers and strengthen local economies. We bring together and support the mobile industry, agricultural sector stakeholders, innovators and investors in the agritech space to launch, improve and scale impactful and commercially viable digital solutions for smallholder farmers in the developing world.

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Context and approach

Climate change is affecting food production through rising temperatures, changing precipitation patterns and greater frequency of extreme weather events, adding to the already pressing challenges to food security in low- and middle- income countries (LMICs). Smallholder farmers, responsible for the food security of two billion people around the world, are severely affected due to their reliance on rainfed agriculture and increasingly disrupted ecosystems. In order to maintain food security and improve rural livelihoods in the face of a changing climate, food systems must adapt to manage and mitigate these increasing challenges.

Climate-smart agriculture (CSA) charts development pathways that achieve three interlinked goals: Increased productivity and profitability, adaptation to climate change and mitigation of climate change. It provides the means to identify, develop and measure practices that enable the transition to sustainable agricultural systems. A number of practices have been identified that are considered climate-smart across regions and crops, including water management, crop tolerance to stress and intercropping. However, adoption of CSA practices by smallholders faces a number of barriers, with unmet training and information needs affecting over 90 per cent of CSA interventions.

Data-driven advisory services (DDAS) draw on a variety of data sources, including satellite imagery, weather information and farm profiles to support the decision-making of smallholder farmers. These services build on conventional, crop calendar-based advisory services to make them responsive to real-time agrometeorological conditions and location-specific challenges. The context-specificity and scalability of DDAS means they present an opportunity to meet the information needs and facilitate the scale up of CSA practices among smallholder famers.
This report distinguishes two types of farmer-facing DDAS: **Precision agriculture (PA)** services that use farm-level data to customise advisory content, and **digital climate advisory services (DCAS)**, which tailor advisory content based on dynamic agroclimatic conditions at the farm location.

India, Kenya and Nigeria have been chosen as focus markets as they are pioneers in agritech innovation, hosting the most, and the most scaled-up, providers of digital agriculture solutions for smallholder farmers. India is showing high levels of innovation in Artificial Intelligence-enabled services for social good, with the highest number of start-ups among LMICs, while Nigeria and Kenya have the highest number in Sub-Saharan Africa (excluding South Africa). All three markets face a range of distinct challenges from climate change and are turning to CSA approaches to address them. Understanding and contrasting the approaches taken and challenges faced by DDAS providers in these markets will provide learnings for DDAS providers across LMICs.

Key findings: Digital climate advisory services for agriculture (DCAS)

DCAS providers across the focus markets can be distinguished between those that provide advisory services as a stand-alone service, and those that offer advisory as part of a bundle of services, typically aimed at digitising value chain activities such as access to inputs, credit and output markets. While these approaches share the core service creation steps, their underlying business models, including partnerships, and revenue generation, differ significantly.

Advisory-only DCAS are typically led by agritechs that provide advisory services or other organisations specialising in content development, such as agricultural research institutes or media companies. Service owners rely on partnerships with agricultural research institutes and weather forecasters to develop content, and with extension services to support user registration. Advisory-only DCAS typically rely on public and donor funding to provide their services, enabling them to serve non-commercial crops and marginalised groups.

Providers of **bundled DCAS** use advisory to enhance the value of their bundled services, typically value-chain digitisation, to farmers. In addition to partnering with agricultural research institutes and weather forecasters for content development, bundled DCAS providers also work with PA services to collect field-level data and customise services. Due to the economies of scale created by bundling services, bundled DCAS can operate agent networks that deliver services to farmers and collect farm-level data. Cross-subsidisation of advisory services from revenue generated by complementary services in the bundle, typically input sales, enables DCAS to be provided to farmers for free.

At the core of service creation, most DCAS are information on the agroclimatic zones of a given area, including soil types and crop suitability, and existing content on applicable good agricultural practices. Self-reported user data captured through digital service delivery channels is used to customise advisory content to the user context. This combination enables advisory content to be tailored to the location of the user, relevant crops and specific point of the cropping cycle.

Remote-sensing satellite data is often used as a complementary data source to customise or develop advisory content, by monitoring crop growth and identifying problem areas. **Weather and climate services**, although crucial to tailoring content to short-term and seasonal conditions, are used relatively infrequently due to a lack of reliable localised weather forecasts. Business models used by bundled DCAS providers enable them to collect field-level data through their **agent networks**, or partnerships with PA providers of services such as **soil testing** and **automated weather stations**. These data sources significantly increase the scope to improve and expand advisory services and customise them to the needs of users.

All services providing outbound services to farmers covered by this research relied heavily on manual **expert assessment** to develop advisory messages. While some service providers employ in-house agronomists, content developed by local research institutes remains a key input, and their representatives often play a role in **quality assurance** of the developed advisory content. The use of **user-centred design** principles to inform service development varies by type of DCAS, and so it is crucial to ensure services are accessible to marginalised groups such as women, farmers with low literacy levels or older persons.

Key findings: Precision agriculture (PA)

The PA space is currently comprised of organisations that specialise in specific technology platforms including Internet of Things (IoT) sensors, mobile soil testing, unmanned aerial vehicles (UAVs) or drones and computer vision analysis delivered through mobile apps. The characteristics of these technologies strongly influence the types of services that can be created, as well as the business models required to commercialise them.

IoT sensor services provide the hardware to collect data on several indicators, as well as services that analyse this data and provide advisory through mobile apps. Data collected by soil sensors on soil moisture, soil temperature, pH and nutrients are compared to ideal values based on crop requirements to make recommendations on irrigation, fertiliser application and pest and disease risk. Advice is typically provided through smartphones to device owners. As high costs prevent direct sale to smallholder farmers, IoT solutions are marketed to commercial farmers, governments and cooperatives which train individuals to operate the hardware and provide services within their farmer groups. Access to the app is provided on subscription-basis.

Soil testing services use mobile labs or handheld sensors to provide soil nutrient measurements to smallholder farmers. A key enabling technology for soil testing services is the use of portable soil scanners using spectroscopy, and machine learning algorithms are trained on large datasets of laboratory-tested soil samples for calibration. This approach has significantly reduced the cost of soil analysis. Similar to IoT services, business models for soil testing services typically involve the sale of soil testing hardware to business clients such as agribusinesses or input providers that provide the services to affiliated farmers.

UAV services use drone-mounted sensors to observe a range of agricultural phenomena, such as plant health, soil moisture and nutrient content, at high resolution. The collected imagery is processed through specialist proprietary software, which overlays it on Geographic information system (GIS) maps and provides reports on agronomic indicators that can be shared with end users. UAV providers market their services to commercial farmers and farmer cooperatives that pay for services rendered, typically a combination of field monitoring and spraying activities. Organisations using **computer vision** to provide pest and disease diagnostics rely on users to collect the relevant data using their smartphone, by taking images of the affected plant. From these images, machine learning algorithms typically developed in-house by the service provider, identify the plant pest or disease and relevant advice is provided to the user. The mobile apps are typically offered free, with business models ranging from donor-funded, to data monetisation to business customers, and cross-subsidisation from bundled services.

Key messages: The contribution of data-driven advisory services to climate-smart agriculture

The short pieces of advice provided by DDAS are well suited to guiding day-to-day agricultural decisions, but less so to facilitate the move to fundamentally different farming practices. The comprehensive advisory and greater potential to scale means DCAS have the greatest potential to support CSA adoption, while PA provides highly localised advice for a limited number of agricultural practices. Bundled DCAS provide the most sophisticated advisory services enabled by field-level data collection, but are limited to commercial value chains. Subsidised advisory-only services can use their mandate to champion agricultural practices and serve groups excluded from commercial services.

Advisory content on CSA practices from agricultural research institutes is a cornerstone of effective DDAS, but not yet widely available.

Research to bridge this gap should:

- Identify and provide advice on agricultural practices that address CSA pillars in local contexts; and
- Develop crop models that integrate the impact of climate factors and extreme climate events.

Accurate and localised weather and climate services are crucial to effective DDAS service creation, but not yet widely available.

Access to improved weather services can be enabled by collaborations with:

- Organisations that can extend in-country weather observations infrastructure, including non-governmental organisations (NGOs) and MNOs; and
- Private weather forecasters using innovative weather modelling or data acquisition to localise their forecasts.

Partnerships between agricultural research institutes and DDAS providers can enable the production and scalable distribution of effective CSA content.

Opportunities to deepen these collaborations to develop and scale up CSA practices include:

- Data sharing by (bundled) DCAS providers with research institutes to enable research and development into CSA practices; and
- Co-creation of CSA practices and advisory packages that lower thresholds to adoption among smallholder farmers.

Partnerships for ground-level data collection and service delivery will increase the impact of advisory-only DCAS.

Opportunities to improve ground-level data collection include:

- Partnering with bundled DCAS providers, where available, to share on-the-ground infrastructure; and
- Building a shared digital agent network for the execution of field-level tasks by organisations serving rural populations.

Bundled DCAS providers are well placed to provide incentives to drive farmer adoption of transformative CSA practices.

Opportunities for DCAS providers to incentivise transformative CSA practices include:

- Using data collected throughout the cropping cycle to enable the traceability of produce required to secure premiums from sustainable produce; and
- Using data collected throughout the cropping cycle to enable the creation and sale of carbon credits from the mitigation impacts of CSA practices.

Impact measurement frameworks developed and implemented by agricultural research institutes and DDAS providers can drive future research in CSA.

Opportunities to improve CSA impact measurement of DDAS provision include:

- The development of clear and standardised impact measurement frameworks to assess adaptation and mitigation impacts; and
- Additional incentives for impact monitoring by DCAS providers to drive widespread adoption.

1
Introduction

Smallholder farmers[1] are responsible for the food security of two billion people around the world,[2] providing 70 per cent of the calories consumed in Asia and Sub-Saharan Africa.[3] Despite their important role in the global food system, they represent a large proportion of the world's poor and often live on less than $2 per day.[4]

Smallholder farmers face numerous challenges, including limited access to financial resources and agricultural inputs, poor social support, poor access to health and education services and the effects of climate change.[5] The productivity of smallholder agriculture, the vast majority of which is rainfed, depends on the services provided by well-functioning ecosystems, including soil fertility, freshwater delivery, pollination and pest control.[6]

Climate change is already affecting food security through rising temperatures, changing precipitation patterns and greater frequency of some extreme weather events.[7] This adds another dimension to the already pressing challenges to food security in low- and middle-income countries (LMICs), including population growth that will increase demand for food,[8] and structural inequalities that make nutritious diets inaccessible to marginalised groups. The projected impacts of climate change will continue to add pressure to food security, with severe implications for crop production, particularly in drylands; significant challenges to fruit and vegetable production due to heat stress in tropical and semi-tropical regions; and threaten already vulnerable pastoral systems in Africa.[9]

Smallholder farmers can adapt to these challenges by adapting or optimising their farming practices, such as adopting more stress-tolerant crop varieties, diversifying their production, increasing soil carbon content and reducing erosion. Such practices will enable farmers to maintain or increase their productivity in the face of changing climatic conditions and more extreme weather events. They also offer them the opportunity to reduce greenhouse gas (GHG) emissions, thereby contributing to climate change mitigation. For example, reduction in emissions from cropping systems can be achieved by adopting practices that sequester carbon in soils or trees, and through reductions in fertiliser use.

Climate-smart agriculture (CSA) was developed as a framework to guide the transition to sustainable agricultural systems in the face of intensifying impacts of climate change. CSA charts development pathways that can help to achieve three interlinked goals: increased productivity and profitability, adaptation to climate change and mitigation of climate change.[10] CSA is not a set of practices; rather, it provides the means to identify, develop and measure practices that enable the transition to sustainable agricultural systems. Since the impact of a given practice is sensitive to contextual factors, such as agroclimatic conditions and socio-economic factors, some practices may be climate smart in one context, but not in another. As such, a wide variety of approaches, including conventional and traditional practices, nature-based solutions and regenerative agriculture, can all contribute to CSA as long as they support the three pillars of CSA.

Over the past decade, an increasing number of digital agriculture services have matured and scaled, helping to create socio-economic impacts for farmers.[11] Often they do this by changing the way things are done. Using mobile communications channels to provide digital advisory services significantly increases the scale and frequency of interactions with farmers; digitally captured procurement transactions enable farmers to prove their creditworthiness and access formal sources of loans; e-commerce platforms and digital aggregation solutions enable smallholder farmers to access markets for inputs and outputs that were previously out of reach; digital service platforms bring together complementary digital solutions that, when bundled, enable fundamental shifts in agricultural activities.

1 Smallholder farmers are defined as those that hold less than two hectares of land.
2 Talukder, B. (2021). Health impacts of climate change on smallholder farmers.
3 Fanzo, J. (2017). From big to small: the significance of smallholder farms in the global food system.
4 World Bank. (2016). A Year in the Lives of Smallholder Farmers.
5 Talukder, B. (2021). Health impacts of climate change on smallholder farmers.
6 IFAD. (2013). Smallholders, food security, and the environment.
7 Mbow, C. et al. (2019). "Food Security". In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.
8 Estimated to be a three-fold increase in Sub-Saharan Africa, and almost two-fold in South Asia. See: WRI. (2019). Creating a Sustainable Food Future.
9 Mbow, C. et al. (2019). "Food Security". In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.
10 FAO. (2017). Climate Smart Agriculture Sourcebook.
11 GSMA. (2020). Digital Agriculture Maps.

Data-driven advisory services (DDAS) enable evidence-based decision-making through the integration of data. DDAS draw on a variety of data sources, including satellite imagery, sensor data, weather data and farm profiles, and use artificial intelligence (AI) and other analysis methods to support the decision-making of smallholder farmers and other value chain actors, such as agribusinesses and input providers. DDAS encompass both macro agri-intelligence services that analyse agricultural activity at a country or regional level for large organisations or public institutions (B2B/B2G),[12] as well as farmer-facing (B2C/B2B2C)[13] services, such as digital climate-informed advisory services[14] or precision agriculture services[15] that use time- and farm-specific data on weather, climate and agronomic variables to provide tailored advice on agricultural practices.[16] These services build on conventional, crop calendar-based advisory services to make them responsive to real-time agrometeorological conditions and location-specific challenges.

The context-specificity and ability to reach large numbers of farmers through digital channels means DDAS present an opportunity to scale up climate-smart agriculture practices among smallholder famers. To enable CSA, several activities need to take place: Research and development of CSA technologies; identification of appropriate CSA technologies for a given context; implementation of CSA technologies; evaluation of the impact of these technologies; and scaling up of CSA practices.[17] Each of these activities requires, or can be enhanced through, the use of context-specific data and/or crop modelling provided by DDAS. For example, one of the main barriers to the adoption of CSA practices by smallholder farmers is a lack of farmer training and information,[18] both of which are inherently addressed by DDAS. This indicates there are significant opportunities for DDAS to enable the adoption of CSA among smallholder farmers.

As satellite observations, Internet of Things (IoT) networks and low-cost sensors have become more available, and machine learning (ML) and computing technology more accessible, DDAS providers have proliferated around the world. India, Kenya and Nigeria are seeing especially high levels of innovation, hosting the most, and the most scaled-up, providers of digital agriculture solutions for smallholder farmers. India is showing high levels of innovation in AI-enabled services for social good, with the highest number of start-ups among LMICs, while Nigeria and Kenya have the highest number in Sub-Saharan Africa (excluding South Africa).[19,20] Funding for digital agriculture start-ups across the three markets also leads their respective regions, with Kenya and Nigeria representing more than 96 per cent of agritech funding in Sub-Saharan Africa.[21] Given the progressive nature of services in these three markets, they are the focus of our research on DDAS in practice.

This report, aimed at DDAS providers and CSA research institutes, illustrates the potential of farmer-facing DDAS to support the adoption of CSA practices among smallholder farmers, and to identify opportunities to maximise this potential in practice. It introduces both the concepts of CSA and DDAS in more detail, outlining links between DDAS advisory and the information required for the adoption of CSA practices. It then tracks DDAS providers in the focus markets, highlighting best practices in DDAS provision and identifying opportunities for DDAS providers to support CSA.

12 Examples of macro agri-intelligence providers: Gro Intelligence, Satelligence and GeoGecko.
13 Business to business to consumer (B2B2C) services enable businesses to provide consumer-facing services.
14 Examples of digital climate advisory services: Esoko, aWhere and FarmNeed.
15 Examples of precision agriculture providers: FarmBeats, BeatDrone and Cropnuts.
16 GSMA. (2021). Digital Innovation for Climate-Resilient Agriculture.
17 FAO. (2016). Planning, Implementing and Evaluating Climate-Smart Agriculture in Smallholder Farming Systems.
18 Mercy Corps. (2020). Digital Climate Smart Agriculture Playbook.
19 World Bank. (2019). Scaling Up Disruptive Agricultural Technologies in Africa.
20 GSMA. (2020). Artificial Intelligence and Start-Ups in Low- and Middle-Income Countries.
21 Disrupt Africa. (2021). The African Tech Startups Funding Report.

1.1 Methodology

This report combines findings from secondary research (literature review) with key informant interviews.

Analysts conducted in-depth semi-structured interviews with roughly 40 stakeholders, including agritech companies, weather and climate services, agricultural research institutes and non-governmental organisations (NGOs). Because of the travel restrictions imposed by the COVID-19 pandemic, interviews were conducted remotely using web-based platforms or telephone. Primary research was corroborated with internal and external secondary sources, both qualitative and quantitative. Internal sources include an extensive library of GSMA reports, toolkits and market assessments, as well as the GSMA AgriTech Services Tracker (see Box 1). External sources for this report include industry-recognised publications, such as by the World Bank, Food and Agriculture Organization (FAO) of the United Nations, CGIAR centres, academic literature on CSA adoption and impact and data-driven agricultural advisory.

Box 1

GSMA AgriTech Services Tracker

The GSMA maintains a tracker of active digital services in agriculture. These services are defined as those that have scaled beyond the pilot stage and have been active for more than one year. The GSMA AgriTech Services Tracker currently includes more than 230 organisations and more than 800 services (as of May 2022).

The tracker is kept up to date with ongoing secondary research that draws on industry publications (e.g. Global Commission on Adaptation (GCA), World Bank, World Meteorological Organization), donor and international NGO websites (CCAFs, CGAP, Mercy Corps, UK Foreign, Commonwealth & Development Office), as well as snowball sampling from informant interviews. Additional sources include service provider websites, relevant case studies and semi-structured interviews. Geographically, the tracker focuses on markets where the GSMA AgriTech programme has a presence: Sub-Saharan Africa, South Asia, Southeast Asia and Latin America.

Chapters 2 and 3 draw on secondary research to conduct a deep dive into the fields of CSA and DDAS. Chapter 2 draws on grey literature from the FAO, World Bank, the CGIAR research program on Climate Change, Agriculture and Food Security (CCAFS) and other organisations leading the research and implementation of CSA, as well as semi-structured interviews with CSA experts. Chapter 3 reviews academic literature on the use of various digital data sources and analysis approaches (e.g. remote sensing, in situ sensors, modelling and AI) to support agricultural decision-making, and outlines the potential contribution of DDAS to the information needs of smallholders adopting CSA practices. Chapter 4 draws on secondary research to sketch the context of DDAS provision and CSA adoption in the focus markets.

Chapters 5 and 6 draw on secondary research from the GSMA AgriTech Services Tracker (see Box 1) and semi-structured key informant interviews with active DDAS providers to landscape DDAS across the focus markets. It uses the concepts developed in chapters 2 and 3 to characterise the types of DDAS provided and identifies key enablers for each type. Variations in the types of approaches to service provision and key enablers across markets are discussed, with reference to the market context laid out in chapter 4, where relevant. Chapter 7 looks at the linkages between DDAS and CSA and identifies opportunities for DDAS to (further) inform the adoption of CSA practices by smallholder farmers.

2
Climate-smart agriculture

The concept of climate-smart agriculture (CSA) was introduced by the FAO in 2010 to address the specific challenges posed by climate change to sustainable food and agriculture.[22] CSA refers to those agricultural practices that contribute to three interlinked goals: Sustainably increasing agricultural productivity and income; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas (GHG) emissions, where possible.[23]

Applying a CSA approach will lead to the transformation of agricultural systems required to support sustainable development and ensure food security in a changing climate. As an approach that is defined by outcomes, it does not advocate specific agricultural practices, as these may be climate smart in one context but not in another. Context-specific impact is key.

In the context of smallholder agriculture in low- and middle- income countries (LMICs), where government or donor interventions introduce CSA, productivity and adaptation typically take priority over climate mitigation. Smallholder agriculture is a key source of livelihood and food security in LMICs. As such, it must be protected by pursuing practices that will increase productivity and protect production from the impacts of climate change, even if these practices do not contribute to the reduction of GHG emissions.

Smallholder farmers produce approximately five per cent of global GHG emissions, mainly from land conversion, rice production and livestock rearing.[24] This small yet significant proportion presents an opportunity for emissions reductions, but should only be pursued when it supports the other two pillars.

The CSA approach has significant overlap with concepts such as sustainable crop production intensification (SCPI),[25] nature-based solutions[26] and regenerative agriculture,[27] which have become increasingly popular and refer to practices that simultaneously address societal and conservation challenges. Indeed, many of the agricultural practices widely considered to be climate smart, such as conservation agriculture, can also be defined as a nature-based solution or regenerative agriculture. This is because an ecosystem service[28] – the natural regeneration of soil – is being used to solve the societal problem of soil fertility, thereby restoring and conserving soil biodiversity while improving agricultural productivity.

This report focuses on the concept of CSA as it deals specifically with the challenges that climate change poses to sustainable development and food security, and casts the widest net in terms of agricultural practices.

Box 2

Climate-smart agriculture practices achieve three key goals:

Productivity

Sustainably increasing agricultural productivity and incomes

Adaptation

Adapting and building resilience to climate change

Mitigation

Reducing and/or removing GHG emissions where possible

22 FAO. (2017). Climate Smart Agriculture Sourcebook.
23 Ibid.
24 Vermeulen, S. and Wollenberg, E. (2017). A rough estimate of the proportion of global emissions from agriculture due to smallholders.
25 Sustainable crop production intensification (SCPI) aims to produce more from the same area of land while reducing negative environmental impacts, conserving natural resources and enhancing healthy ecosystem services.
26 The IUCN defines nature-based solutions as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". See: www.iucn.org/theme/nature-based-solutions.
27 Regenerative agriculture is "a holistic agricultural approach that retains, or if needed restores, ecosystems to a healthy and resilient state by improving the soils while providing sufficient return to build up impact in different dimensions towards sustainability (environment, income, jobs)." Meulensteen, T. and Duurland, T. (27 November 2020). "Transitioning to regenerative agriculture with smallholders". IDH – The Sustainable Trade Initiative Blog.
28 Ecosystem services are the benefits people derive from ecosystems, including the provision of food, wood and other raw materials, as well as the essential regulating services such as pollination of crops, prevention of soil erosion, water purification, and cultural services such as recreation and spiritual fulfillment. See: Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well-being: Synthesis.

2.1 Climate-smart agricultural practices

Although climate-smart practices are highly context-dependent, several are broadly applicable across regions and crops.

A recent World Bank study[29] captures these practices and their contribution to the three pillars of CSA (see Table 1). These contributions will vary across contexts and should be viewed as an illustration of the potential of agricultural practices to satisfy the criteria of 'climate smartness', not as a definitive list of climate-smart technologies.

Table 1

Climate-smartness of CSA practices

CSA practice	Productivity	Adaptation	Mitigation
Water management	High	Very high	Medium
Crop tolerance to stress	Medium	Medium	Low
Intercropping	Medium	High	Medium
Organic inputs	Medium	Medium	Medium
Conservation agriculture	High	Very high	High
Fertiliser management	Medium	Medium	Medium
Integrated pest management	High	Medium	Medium
Climate services	Medium	Medium	Low

Low · Medium · High · Very high

Source: Adapted from the 2018 World Bank report, Bringing the Concept of Climate-Smart Agriculture to Life.

While these practices are presented in isolation, they are closely connected, and for any to achieve its full potential it must be implemented within a farming systems approach that combines complementary practices. This section introduces those most widely regarded climate-smart practices to illustrate how CSA works in practice and to identify CSA practices enabled or supported by data-driven advisory services (DDAS) (see chapter 3).

29 World Bank. (2018). Bringing the Concept of Climate-Smart Agriculture to Life.

2.1.1 Water management

Water management practices

- Efficient irrigation technologies;
- Water harvesting;
- Drainage and flood management;
- Soil moisture retention enhancement;
- Adapting crops and the cropping calendar; and
- Improved weather forecasting.

Most impacts of climate change on agriculture will result from changes in the water cycle that increase desertification, make rainfall less predictable and contribute to more frequent and extreme drought and heavy rainfall events.

Adaptation to extremes of rainfall and drought requires optimal use of available water. This includes selecting water-efficient crops/varieties, timing cropping cycles using improved weather forecasts and using efficient irrigation technologies.

Land management approaches to optimise water use include harvesting rainwater, improving drainage on cultivated land while reducing erosion and increasing soil moisture retention for long-term resilience.

Figure 1

Planting pits, or Zai pits, are used in (semi-)arid areas to retain water for crop production.

Source: Jake Lyell / Alamy Stock Photo

2.1.2 Crop tolerance to stress

Characteristics of stress-tolerant crops

- Nutrient and water-use efficiency;
- Tolerance to environmental stresses such as drought, water logging, acid soil, salinity, frost and other abiotic factors; and
- Resistance to crop disease.

As the pace of climate change exceeds the pace at which natural systems can adapt, crop varieties that are tolerant of new climate extremes and require fewer inputs will enable both adaptation and mitigation. Resilient crop varieties may be developed through breeding, genetic modification or by (re)discovering suitable native varieties.

Based on seasonal and longer term climatic outlooks, there is a continuous need to assess which crop (varieties) will be most suited to cultivation in a particular location to maximise productivity.

2.1.3 Intercropping

Intercropping practices

- Intercropping with nitrogen-fixing crops;l
- Perennial crops and trees/shrubs in farm landscape; and
- Agroforestry.

Intercropping refers to cultivating more than one crop at a time arranged in a geometric pattern, typically by planting two crops in alternating rows.[30] It has the potential to address a variety of challenges that can support both climate adaptation and mitigation.

Intercropping with nitrogen-fixing crops like peas and beans or with trees like faidherbia can improve soil fertility and yields. The use of perennial crops and trees on land where seasonal crops are cultivated can improve soil resilience, reduce erosion, provide shade and improve water quality, providing additional products such as food, fuel, fibre and timber. Since perennial crops and trees can sequester more carbon for longer than annual crops, they can improve the carbon mitigation capacity of the cultivated land. Reducing tillage with annual crops also increases soil carbon content. The integration of trees in cropland has one of the highest mitigation potentials of nature-based solutions in agriculture and grasslands.[31]

Figure 2

Intercropping, in this case with trees and cereals, provides various benefits for productivity and adaptation, and has significant carbon sequestration potential.

Source: Technical Centre for Agricultural and Rural Cooperation (CTA)

30 FAO. (1995). Glossary.
31 Miralles-Wilhelm, F. (2021). Nature-based solutions in agriculture – Sustainable management and conservation of land, water, and biodiversity. FAO and The Nature Conservancy.

2.1.4 Organic inputs

Examples of inputs in organic agriculture

- Compost, crop residues, organic manure; and
- Organic/botanical pesticides.

Organic agriculture is an agricultural system that relies on ecosystem management rather than external inputs such as synthetic fertiliser and pesticides.[32] Inputs used in organic agriculture systems include manure, urea and compost for fertilisation, as well as organic or botanical pesticides.

The use of organic inputs contributes to soil structure, biotic function, nutrient availability and soil carbon content. This improves the resilience of agriculture in the medium to long term. As land becomes more naturally fertile, it is better able to manage water stress (through improved water retention and reduced erosion) and natural resistance to crop pest and disease.

2.1.5 Conservation agriculture

Conservation agriculture principles

- Minimum soil disturbance;
- Maintenance of permanent soil cover; and
- Crop rotations with a diversity of crop species.

Conservation agriculture (CA) aims to improve agricultural yields through strengthening biological processes that improve soil quality.[33] It is based on three key principles of minimum soil disturbance (i.e. no tilling), maintaining permanent soil cover (e.g. cover crops, mulching) and crop rotations with a diversity of crop species (e.g. to enhance fertility and reduce the risk of pests and disease).

By providing sufficient organic matter and avoiding soil disturbance, soil microfauna can improve soil nutrients and water infiltration and retention, and reduce soil erosion, thus contributing to adaptation. Increased soil carbon content contributes to significant soil carbon sequestration, and, in turn, greater climate change mitigation impacts.

Figure 3

Maintaining permanent soil cover, here through mulching, contributes to the natural restoration of soil fertility, water retention and carbon content, among other benefits.

Source: Guy Thibaud/KZN DARD

Crop rotation and reduced soil disturbance have both been recognised as practices that, when applied by themselves, have significant CSA impacts in a wide range of contexts.

32 FAO Organic Agriculture Programme: www.fao.org/organicag/oa-home/en/.
33 European Conservation Agriculture Federation. (2015). What is Conservation Agriculture?

2.1.6 Fertiliser management

Fertiliser management approaches

- Composition and application rate, for example, site-specific nutrient management, micro-dosing, seed priming; and
- Timing and placement of fertiliser application, for example, deep placement and zai/planting pits.

Excessive use of inorganic nitrogen fertiliser is one of the key sources of GHG emissions from agriculture, due to microbes in the soil converting excess nitrogen into nitrous oxide, a potent GHG. Runoff of excess fertiliser contaminates waterways and causes eutrophication. The overuse of synthetic fertilisers also contributes to soil acidification, reduces organic matter and humus content, decreases beneficial species while increasing pests and stunts plant growth, all of which impact productivity.[34]

Better fertiliser management, which applies the right amount in the right composition at the right time and place, can significantly reduce these negative effects while also reducing input costs and improving productivity.

Figure 4

Fertiliser micro-dosing is an approach that minimises fertiliser use while improving productivity.

Source: African Plant Nutrition Institute (APNI)

2.1.7 Integrated pest management

Integrated pest management

- Develop resilience to biotic stress[35] through biodiversity and soil health; and
- Approaches include mulching, minimum tillage, intercropping.

Integrated pest management, or IPM, promotes biological control of pests and diseases, good agronomic practices and the use of other means to control pests besides chemical pesticides. It is based on four practical principles: 1) growing a healthy crop, 2) conserving natural predators, 3) observing fields regularly and 4) farmers becoming experts.[36]

Changing climatic environments are anticipated to cause an overall pattern of increasing crop pests. IPM decreases negative impacts on the broader ecosystem, making farming systems more resilient. IPM also contributes to the efficiency of agricultural production and input use, reducing associated emissions.

34 Bisht, N. and Chauhan, P.S. (2020). Excessive and Disproportionate Use of Chemicals Cause Soil Contamination and Nutritional Stress.
35 The damage caused to plants by other living organisms, such as parasites and pathogens (virus, bacteria, fungi, nematodes or insects), brings about what is known as biotic stress. See: Gimenez, E. et al. (2018). Worldwide research on plant defense against biotic stresses as improvement for sustainable agriculture.
36 FAO. (2017). Integrated Pest Management Group for sustainable production and marketing in Iran.

2.1.8 Climate services

Climate services

- Accurate weather and climate forecasts.

Climate services are key to agricultural decision-making,[37] from seasonal forecasts informing crop choices and timing of planting, to weather observations and forecasts feeding into pest/disease early warnings, to daily forecasts informing fertiliser application. Accurate climate services enable agricultural practices to be adapted to changing climatic conditions, improving the efficiency of agricultural production and contributing to sustainable intensification.

2.2 Assessing the impact of climate-smart agriculture

Agricultural practices are defined as climate-smart depending on their ability to improve productivity, increase resilience and reduce emissions.

The ability to assess whether these objectives are being met is therefore crucial. Assessment of impact will enable the identification of impactful practices, quantification of return on investments and the contribution of CSA interventions to climate-related targets. For agricultural research institutes, impact assessments are integral to identifying appropriate CSA technologies in particular contexts,[38] but the evaluation of the impact of CSA practices adopted by farmers is much less well established.

There are various approaches to measuring the impact of CSA, each of which provide definitions and methodologies for the three pillars of CSA.[39] **Sustainably increasing production and incomes** is often translated into a quantitative measure of production, yet would benefit from expanding the scope to include food security indicators not directly related to productivity or income. **Adapting and building resilience to climate change** is the least well defined in measurement frameworks, with short-term adaptation to climate-related shocks and long-term adaptation to a gradually changing climate either not clearly distinguished or not equally represented. The comparison of adaptation measures across studies can be facilitated by controlling for basic socio-economic characteristics that influence households' coping and adaptation behaviour. **Reducing and/or removing greenhouse gas (GHG) emissions** can be quantified using emission factors of key GHGs from agricultural practices[40] or from continuous observations that track changes before and after interventions. Arguably, the scope of mitigation could be expanded to include impact on relevant ecosystem services.

Frameworks to put these measurement approaches into practice are being provided by the major international institutes active in this space. The CGIAR provides resources for the identification of climate-smart agricultural technologies through a searchable database of agricultural research data,[41] and a rapid appraisal tool,[42] as well as a practical tool for tracking the outcomes of CSA interventions.[43] The FAO also provides a range of tools[44] that can support CSA outcome assessments to guide decision-making or measurement. These cover a variety of topics and perspectives, including climate risk management, gender mainstreaming and economic and policy analysis. To maximise the lessons of impact assessments of CSA interventions, assessment frameworks should be standardised or consolidated to facilitate comparisons of different approaches.

37 Born, L. et al. (2021). A global meta-analysis of climate services and decision-making in agriculture.
38 FAO. (2016). Planning, Implementing and Evaluating Climate-Smart Agriculture in Smallholder Farming Systems.
39 Van Wijk, M.T. et al. (2020). Improving Assessments of the Three Pillars of Climate Smart Agriculture: Current Achievements and Ideas for the Future.
40 FAO. (2015). Estimating Greenhouse Gas Emissions in Agriculture.
41 Evidence for Resilient Agriculture (ERA): https://era.ccafs.cgiar.org/.
42 CIAT. (2015). Climate-smart Agriculture Rapid Appraisal (CSA-RA) Prioritization Tool.
43 CCAFS. (2016). CSA Programming and Indicator Tool: 3 Steps for increasing programming effectiveness and outcome tracking of CSA interventions.
44 FAO. (n.d.). "Climate-Smart Agriculture: Methods and Assessments".

2.3 Barriers to smallholder adoption of climate-smart agriculture

Despite the multiple benefits of CSA for smallholder farmers, the adoption of CSA practices is too low to successfully adapt to and mitigate the impacts of climate change. While governments across LMICs have increasingly subscribed to the 17 United Nations Sustainable Development Goals (SDGs), and are increasingly addressing the threat of climate change, policies to put these ambitions into practice are typically lacking.[45] There has been some involvement of the private sector to support adoption of CSA among smallholder farmers (typically to achieve certification) as part of corporate social responsibility (CSR) efforts or to mitigate supply chain risks. However, greater private sector involvement is often cited as crucial to more widespread adoption.[46,47,48] To better understand how adoption of CSA practices can be increased among smallholder farmers, this section provides a brief overview of challenges identified by farmers themselves.

Capacity needs in the form of **training and information** have been identified as a barrier affecting more than 90 per cent of CSA interventions.[49] This can be at the level of research institutions and extension agencies, which do not have the capacity to develop and/or identify relevant CSA practices for their contexts and disseminate them to smallholder farmers.[50] Developing CSA strategies requires both an understanding of the climate challenges facing different areas of agricultural production and the options and efficacy of practices to address these challenges.[51] In contexts where appropriate strategies have been formulated, these must be communicated to smallholder farmers to build awareness, expertise and trust in the practices to be implemented. In typical LMIC contexts, where extension and advisory services are limited, this is challenging, especially for CSA practices that require substantial behaviour change and time, such as CA and water management.[52,53] Breaking these complex practices down into manageable steps that require less resources to implement can reduce this barrier and is often more in line with the stepwise approach taken by farmers to adopt complex CSA practices.[54]

Perceived risks and benefits of CSA practices also play a significant role in adoption. Like the need for training and information, smallholder farmers need to recognise the value of the practices being proposed and perceive them as outweighing the risks. Some CSA practices, such as CA and agroforestry, require several years of potential losses before benefits are realised. In contexts where farmers have little savings and limited or no access to credit, there is little incentive or capacity to invest in an uncertain future.[55,56] Similarly, practices such as cover cropping and water management may reduce yields in some contexts due to competition between cover and main crops, and in years of excess rainfall, respectively.[57] Such experiences will reduce trust in the efficacy of the practice and can affect uptake. Farmers may have existing opinions of CSA practices as traditional and therefore undesirable.[58] In other cases, CSA may conflict with existing practices; for example, the practice of mulching may be problematic in contexts where crop residues are used for other purposes, such as livestock feed or cooking fuel.[59] CSA practices have been shown to be perceived more positively when they offer multiple benefits (e.g. agroforestry may provide food, fodder and fuel)[60] and in contexts where other related CSA practices have already been successfully adopted.[61]

45 FARA. (2021). Upscaling Climate-Smart Agriculture (CSA) Adoption in Africa.
46 FCDO. (2021). Climate smart agriculture: a thematic review.
47 FARA. (2021). Upscaling Climate-Smart Agriculture (CSA) Adoption in Africa.
48 Kombat, R. et al. (2021). A Review of Climate-Smart Agriculture Technology Adoption by Farming Households in Sub-Saharan Africa.
49 World Bank. (2018). Bringing the Concept of Climate-Smart Agriculture to Life.
50 Kombat, R. et al. (2021). A Review of Climate-Smart Agriculture Technology Adoption by Farming Households in Sub-Saharan Africa.
51 FAO. (2016). Planning, Implementing and Evaluating Climate-Smart Agriculture in Smallholder Farming Systems.
52 FCDO. (2021). Climate smart agriculture: a thematic review.
53 McCarthy, N. et al. (2011). Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation.
54 Rodenburg, J. et al. (2020). Adoption by adaptation: moving from Conservation Agriculture to conservation practices.
55 Ibid.
56 FAO. (2016). Planning, Implementing and Evaluating Climate-Smart Agriculture in Smallholder Farming Systems.
57 McCarthy, N. et al. (2011). Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation.
58 Kombat, R. et al. (2021). A Review of Climate-Smart Agriculture Technology Adoption by Farming Households in Sub-Saharan Africa.
59 McCarthy, N. et al. (2011). Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation.
60 Ibid.
61 Kurgat, B.K. et al. (2020). Adoption of Climate-Smart Agriculture Technologies in Tanzania.

Once awareness of CSA practices and trust in their benefits have been established, adoption may be hindered by unattainable **input requirements**. Practices such as agroforestry and water management require significant investments in labour, seedlings, specialist equipment and/or construction materials,[62,63,64] and financing is typically not available to cover these costs.[65,66] Other practices, such as conservation agriculture or intercropping, may require specific inputs that simply are not available in local markets.[67,68]

Other barriers relate to more **institutional factors**, such as community rules and the cost of collective action. Poorly defined community rules and regulations and/or enforcement around land use issues, such as animal grazing post-harvest, crop residue burning and forestry management, may deter the adoption of practices that would be impacted by unregulated actions.[69,70] Collective action may be required for CSA practices like soil and water management where the impact is only realised when most of the community is involved. In contexts where the community cannot afford to adopt such practices, they will not gain traction.[71]

62 McCarthy, N. et al. (2011). Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation.
63 FCDO. (2021). Climate smart agriculture: a thematic review.
64 FAO. (2016). Planning, Implementing and Evaluating Climate-Smart Agriculture in Smallholder Farming Systems.
65 Ibid.
66 Kombat, R. et al. (2021). A Review of Climate-Smart Agriculture Technology Adoption by Farming Households in Sub-Saharan Africa.
67 McCarthy, N. et al. (2011). Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation.
68 McCarthy, N., Brubaker, J. (2014). Climate-Smart Agriculture and Resource Tenure in Sub-Saharan Africa: a conceptual framework.
69 Ibid.
70 FAO. (2016). Planning, Implementing and Evaluating Climate-Smart Agriculture in Smallholder Farming Systems.
71 McCarthy, N. et al. (2011). Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation.

3

Data-driven advisory services for decision-making

Digital advisory services have been shown to be a cost-effective way to improve yields and influence the adoption of beneficial agricultural practices,[72] as well as improve farmers' ability to plan production and deal with weather-related risks.[73] Integrating local and real-time data sources in advisory services will build on these positive impacts by providing advice that is customised to farm location, length of the cropping season and farmers' characteristics.

Data-driven advisory services (DDAS) integrate a variety of data sources, including satellite imagery, sensor data, weather data and farm profiles, and use artificial intelligence (AI) and other analysis methods to support the decision-making of smallholder farmers and other value chain actors, such as agribusinesses and input providers. The highly contextualised information that DDAS provides is key to identifying and implementing climate-smart agriculture (CSA) practices, which gives them potential to enhance the climate resilience of smallholder farmers and reduce greenhouse gas (GHG) emissions, as well as increase their productivity.

DDAS encompass both macro agri-intelligence services that analyse agricultural activity at a country or regional level for large organisations or public institutions (B2B/B2G)[74] as well as farmer-facing (B2C /B2B2C) services[75] that use time- and location-specific data to provide tailored advice on agricultural practices.[76] This report looks at two types of farmer-facing DDAS: **Precision agriculture (PA)** services that use farm-level data to customise advisory content, for example, drone imagery to identify problem areas in a field and identify appropriate interventions; and **digital climate advisory services (DCAS)**, which tailor advisory content based on dynamic agroclimatic conditions at the farm location, for example, information on soil type, crops cultivated, length of cropping cycle and weather forecasts, enables relevant advice at the right time on planting, input application, crop management and harvesting.

DDAS have been evolving rapidly in recent years, and different terminology has been used for the services. Data-driven agriculture is typically understood in terms of the definition provided in the previous paragraph,[77,78] although the term is sometimes used to refer more generally to any digital agriculture solution that can benefit from farmer and farm data,[79] or more specifically to marketplaces for agricultural data.[80] The most common definition of precision agriculture is providing customised crop- and (sub-)field-level advice based on various data sources, mainly farm-level data.[81,82,83] There are variations in terms of scale, and precision agriculture can also refer to any advisory service tailored to the agroclimatic conditions of a farm[84] or exclusively to the use of data generated on a farm.[85] Services that tailor agricultural advisory to agroclimatic conditions are also known as digital climate(-informed) advisory services (DCAS),[86,87] climate information services (CIS)[88] and precision agriculture or PA.[89]

DDAS services are undergoing rapid evolution, fuelled by the increasing availability of (big) datasets and digital data collection approaches, as well as powerful analysis approaches including modelling and machine learning. To understand and define the resources and activities crucial to this field, this chapter outlines the steps involved in the creation and delivery of DDAS. Applying this framework to the landscaping of DDAS (see chapters 5 and 6) will allow gaps to be identified in current service offerings. This chapter also provides an overview of the types of agricultural decisions DDAS can support throughout the cropping cycle, and then reconciles the information requirements of CSA practices with the agricultural decisions DDAS can support. This will provide an initial framework for understanding how DDAS-supported decision-making can enable the adoption of CSA practices.

72 Fabregas, R. (2019). Realizing the potential of digital development: The case of agricultural advice.
73 Baumuller, H. (2018). The little we know: An exploratory literature review on the utility of mobile phone enabled services for smallholder farmers.
74 Examples of macro agri-intelligence service providers: Gro Intelligence, Satelligence and AtlasAi.
75 Examples of farmer-facing DDAS: iShamba, IFFCO Kisan GreenSIM and Plantix.
76 GSMA. (2021). Digital Innovation for Climate Resilient Agriculture.
77 USAID. (2018). Digital Farmer Profiles: Reimagining Smallholder Agriculture.
78 Global Forum on Agricultural Research and Innovation (GFAR). (2018). Digital and Data-Driven Agriculture: Harnessing the Power of Data for Smallholders 2018.
79 Technical Centre for Agricultural and Rural Cooperation (CTA). (2020). Data-driven opportunities for farmer organisations.
80 World Economic Forum (WEF). (2021). Artificial Intelligence for Agricultural Innovation.
81 USAID. (2018). Digital Farmer Profiles: Reimagining Smallholder Agriculture.
82 Mercy Corps. (2020). Digital Climate Smart Agriculture Playbook.
83 IBRD. (2019). Future of Food: Harnessing Digital Technologies to Improve Food System Outcomes.
84 Technical Centre for Agricultural and Rural Cooperation (CTA). (2019). The Digitalisation of African Agriculture Report.
85 Global Forum on Agricultural Research and Innovation (GFAR). (2018). Digital and Data-Driven Agriculture: Harnessing the Power of Data for Smallholders 2018.
86 Global Center on Adaptation (GCA). (2021). A Blueprint for Digital Climate-Informed Advisory Services: Building 300 Million Small-Scale Producers by 2030.
87 World Business Council for Sustainable Development (WBCSD). (2021). Digital Climate Advisory Services (DCAS) for smallholder resilience.
88 Practical Action. (2020). Climate Information Services Toolkit.
89 Technical Centre for Agricultural and Rural Cooperation (CTA). (2019). The Digitalisation of African Agriculture Report.

22

3.1 From data to data-driven services: Steps in service creation

This section presents a high level framework of the data, analysis methods, infrastructure and activities involved in the creation of DDAS services.

In the landscaping of DDAS in the three target markets of India, Kenya and Nigeria (see chapters 5 and 6), this framework enables the identification of key service enablers, as well as underutilised assets and activities. The framework consists of four steps:

1. **Data collection** – sourcing the data required to develop advisory services. This includes collecting or accessing primary data and/or identifying and accessing relevant secondary datasets and information.
2. **Data analysis** – combining the collected data sets for analysis using one or more methods, including machine learning or AI, or modelling approaches. Advances in the provision of cloud services and analysis software have greatly reduced the initial investments required to apply these approaches.
3. **Content development** – drawing on the collected data and analysis outputs to formulate, tailor and format advisory content for delivery to farmers. This step will ideally involve user-centred design approaches to understand the requirements and abilities of the targeted user groups, and expert assessment that safeguards the efficacy of advice provided.
4. **Service delivery** – using one or more communication channels to deliver content to end users.

Figure 5

DDAS service creation activities

Data collection

PRIMARY DATA
- Remote sensing
  - Satellite
  - Unmanned aerial vehicles (UAVs)
- Sensors
  - Automated weather stations (AWS)
  - Soil sensors
  - Soil testing
  - Computer vision
- Survey
  - Enumerated
  - Self-reported
  - Crowdsourced
- Service-generated data
  - Usage data
  - Metadata

SECONDARY DATA
- Agronomic research data
  - Experimental data
  - Geographic information system (GIS) data
- Advisory content
  - Good agricultural practices
  - Peer-to-peer content
- Weather and climate data
  - Observations
  - Weather forecasts
  - Climate prediction
- Socio-economic data

Data analysis

MACHINE LEARNING/ (AI)

MODELLING
- Crop
- Pest and disease
- Emissions

SOFTWARE AND CLOUD SERVICES
- Cloud computing
- Analysis software

Content development

USER-CENTRED DESIGN

CONTENT LOCALISATION

EXPERT ASSESSMENT

CONTENT FORMATTING

QUALITY ASSURANCE

Service delivery

FACE-TO-FACE
- Extension visits
- Farmer field schools

BASIC PHONES
- Call centres
- Interactive voice response (IVR)
- Short message service (SMS)
- Unstructured supplementary data service (USSD)

SMARTPHONES
- Apps
- Audio-visual content
- Messaging

DDAS SERVICE DEVELOPMENT ACTIVITIES →

3.1.1 Data collection

More data is becoming available for use in DDAS services through advances in primary data collection, including satellite remote sensing, the use of sensors for on-the-ground data collection, digitised survey methods and the harvesting of data from digital service usage. Data from secondary sources, such as agricultural research institutes, weather and climate forecasters and household and economic surveys, are becoming increasingly available through initiatives such as GODAN[90] and the Africa Information Highway[91] that digitise and publish these datasets as open data. Table 2 provides an indicative rating for each data source based on its availability, cost to access, potential impact for advisory creation, and expertise required for interpretation. Each data source is discussed in more detail below.

Table 2

An indicative rating of data sources[92]

	Availability	Predictive capacity	Acquisition cost	Capacity requirement
	(Higher = better)		*(Lower = better)*	
PRIMARY DATA				
Remote sensing				
Satellite	High	Medium	High	Medium
Unmanned aerial vehicles (UAVs)	Low	High	Low	Low
Sensors				
Automated weather stations (AWS)	Low	High	Low	Medium
Soil sensors	Low	Medium	Low	Medium
Soil testing	Low	High	Low	Low
Computer vision	Low	High	Medium	Low
Survey				
Enumerated	Medium	Medium/High	Low/Medium	High
Self-reported	Medium	Low	High	High
Crowdsourced	Low	Medium	Medium	Low
Service-generated data				
Usage data	Medium	Medium	High	Low/Medium
Metadata	Medium	Medium	High	Low/Medium
SECONDARY DATA				
Agronomic research data				
Experimental data	Low/Medium	Medium	High/Medium	Medium
Geographic information system data	Low/Medium	Medium	High/Medium	Medium
Advisory content	Low/Medium	High	High/Medium	High
Weather and climate data	Low	High	Low/Medium	Medium
Socio-economic data	Low	Medium	Low/Medium	Low/Medium

Low Medium High   Low Medium High

90 Global Open Data for Food and Nutrition (GODAN).
91 African Development Bank Group (AfDB) data portal.
92 Based on the author's judgement

Primary data

Unmanned aerial vehicles (UAVs), or drones, contribute to satellite datasets by providing similar data but at a much higher resolution and limited scale.[93] UAVs improve data acquisition by enabling data capture at much closer range, below cloud cover and at a time and frequency that can be determined by the UAV operator (whereas satellites have fixed and often infrequent revisit intervals). The improved resolution of UAVs, operating at centimetre scales as opposed to metre scales, enables observation of new phenomena, such as identification of crops and weeds in fields with mixed vegetation, and observations of soil nutrients that enable tailored fertiliser application. While the costs of equipment and service provision continue to be a challenge, numerous digital agriculture initiatives are using UAVs to have a positive impact on smallholder agriculture.[94]

Figure 6

UAVs provide high-resolution remote-sensing data to enable precision agriculture services.

Source: Agridrones solutions Israel

Figure 7

IoT sensors can provide a variety of observations, including soil moisture and weather.

Source: TAHMO.org

Sensors that use Internet of Things (IoT) networks are becoming increasingly affordable and organisations are beginning to explore services for smallholder agricultural systems. In situ sensors typically include **soil sensors** that measure a variety of soil characteristics, including soil moisture, temperature, pH and salinity; and **automated weather stations** (AWS) that measure various meteorological indicators, including precipitation, temperature and humidity. Innovation in **portable soil scanners** using spectroscopy[95] has drastically reduced the cost and time required to conduct soil composition analysis and is driving efforts to measure and classify soils across the planet.[96] Smartphone cameras coupled with **computer vision** are increasingly being used in the identification of crop pests and disease and are made accessible through freely available mobile apps.[97]

93 African Union (AU) and New Partnership for Africa's Development (NEPAD). (2020). Drones on the Horizon: Transforming Africa's Agriculture.
94 For example: Flying Labs.
95 Global Soil Laboratory Network (GOSOLAN).
96 University of Sydney. (2020). Global soil library will help us better know the living skin of planet earth.
97 For example: Plantix.

Developments in the availability of **remote-sensing data** from satellite missions, such as the National Aeronautics and Space Administration's (NASA) Landsat,[98] the European Union's Copernicus[99] and the Indian Space Research Organisation's (ISRO) Bhuvan,[100] have been key to the development of DDAS. Remote sensing involves using raw data from remote-sensing instruments, which typically measure electromagnetic radiation, to model traits or characteristics of interest, such as crop types, soil moisture and biomass. The freely available data from these sources, including earth observation imagery, land use classifications and indices such as NDVI,[101] has enabled innovation in a range of agricultural monitoring and advisory applications. This field continues to develop rapidly, with satellite agencies improving data-capture instruments to create increasingly high-resolution data products that can improve the quality and expand the use cases of satellite data-enabled agricultural services.

Data on farmers and farming activities is often collected through **surveys**, which are typically conducted face-to-face or through phone calls with enumerators. Digital data capture has improved data input and aggregation while digital communications channels have enabled new approaches to data collection. **Self-reporting** by users on key characteristics through interactive voice response (IVR), short message service (SMS) or unstructured supplementary service data (USSD), are approaches to data collection through basic feature phones. Smartphones provide additional opportunities for data collection through forms, chatbots and integrated sensors such as cameras and GPS. Digital communications have also enabled crowdsourcing of information where a group of people share specific information at the request of a central organiser.[102] Crowdsourcing applications have focused on tracking pest and disease outbreaks and verifying local weather information. In earth observations, **crowdsourcing** (also known as citizen science) is often used to recruit volunteers to label large datasets of satellite imagery (e.g. on crop type), which can then be used as training sets for machine learning algorithms.[103]

Service usage data and metadata are created through the interaction of users with digital services and relates to both the content of the interaction (**usage data**), as well as the data describing the interaction (**metadata**). For example, in producer-buyer relationships where the purchasing process has been digitised (e.g. using a digital procurement solution), the information entered into the system to record crop purchases (e.g. seller, buyer, crop, quantity, price) is the usage data, while the data automatically generated by the entry (e.g. time, date, location, agent, time taken to record transaction) is the metadata. The data generated by such transactions can help tailor advisory services by understanding where specific crops are grown, relative yields of crops and timing of agricultural activities. Pull-based advisory services provide similar insights by analysing demand patterns for advisory on specific crops, cropping activities and pest and disease, across locations and time, provide insights to tailor advisory messaging and recognise early signs of pests.[104]

Secondary data

Agronomic research data typically consists of knowledge outputs from international and national agricultural research institutes. This includes the results of agricultural research, such as field trials or laboratory research that is typically published in peer-reviewed journals. To make the lessons of this vast body of research more accessible, efforts such as the Evidence for Resilient Agriculture (ERA)[105] initiative are making results searchable and comparable in online databases. Geographic information system (GIS) research outputs can also make research more actionable and include **soil maps**[106] that map soil data including physical and chemical properties, and **crop suitability maps**[107] that identify crops most suitable to for growth in specific agroclimatic zones, often taking predicted changes in climate into account.

98 U.S. Geological Survey Landsat.
99 Copernicus.
100 Indian Space Research Organisation (ISRO).
101 Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). See: https://gisgeography.com/ndvi-normalized-difference-vegetation-index/.
102 USAID. (2013). Crowdsourcing Applications for Agricultural Development in Africa.
103 Mazumdar, S. (2017). Citizen Science and Crowdsourcing for Earth Observations: An Analysis of Stakeholder Opinions on the Present and Future.
104 Interview with CIAT (Ani Ghosh).
105 Evidence for Resilient Agriculture (ERA) dataset and web portal: Agricultural Decisions, Rooted in Data.
106 For example, SoilGrids and iSDAsoil.
107 Peter, B.G. et al. (2020). Crop climate suitability mapping on the cloud: a geovisualisation application for sustainable agriculture.

Several initiatives have drawn on agricultural research and practical experience to develop libraries of good agricultural practices and **advisory content** that agricultural extension organisations can use to train and inform farmers. The open access online platform Sprout[108] has recently been launched and provides digital-ready content. CABI[109] is a long-standing international non-profit organisation that provides scientific knowledge to support agriculture and provides a mix of open and private content. Other sources of agricultural content include national extension services that may have advisory content tailored to the farming communities they serve.

There are a variety of **weather and climate data sources** that focus on different timescales.[110] The shortest is precipitation **nowcasting**, which provides high-resolution forecasts of rainfall for the coming six hours.[111] It is typically based on weather radar, although nowcasting services based on satellite data are also being explored[112] and would make this service available in low- and middle- income countries (LMICs) that do not have working radar systems. Numerical **weather forecasts** provide predictions for a range of weather variables up to one month in the future. They are typically provided by global models[113] downscaled to local contexts by national or private weather services, although these services may also be running their own regional models. Climate predictions provide forecasted weather trends over the coming months or years and are based on changes in key indicators, such as ocean temperatures and the El Niño-Southern Oscillation Cycle.[114]

Socio-economic data, such as household surveys, poverty indicators and market information, enable understanding of the social and economic factors that may influence the uptake of agricultural advice. **Household surveys**, typically conducted by governments or (international) non-governmental organisations (NGOs), provide data on a variety of indicators using a standardised methodology.[115] Other approaches to collecting data on **poverty indicators** include using a combination of remote sensing and machine learning that infers poverty from image features.[116] Data on agricultural markets is available from commodity exchanges or extension services for the major markets and crops where these are active,[117] and INGO-led global platforms provide transparency on food markets to track global trends.[118] Market information can also include databases of relevant agricultural stakeholders like input providers or processors. For example, the Nigerian Seed Portal Initiative[119] provides information on improved seed varieties for the most common crops, as well as the contact details for seed companies across Nigeria. Databases of smallholder farmers, typically held by farmer organisations, extension services, NGOs or agribusinesses, are crucial enablers of DDAS service localisation and delivery.

108 Sprout.
109 Centre for Agriculture and Bioscience International (CABI).
110 World Meteorological Organization (WMO). (2015). Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services.
111 WMO. (2017). Guidelines for Nowcasting Techniques.
112 Roberts, A. et al. (2021). Challenges and Solutions to nowcasting for Africa.
113 For example, the European Centre for Medium-Range Weather Forecast and National Centers for Environmental Information.
114 European Forest Fire Information System (EFFIS).
115 For example, The World Bank's Living Standards Measurement Study (LSMS).
116 Jean, N. et al. (2016). Combining satellite imagery and machine learning to predict poverty.
117 For example, Nigeria Commodity Exchange.
118 Agricultural Market Information System.
119 Nigerian Seed Portal Initiative.

3.1.2 Data analysis

Data from primary and secondary sources needs to be analysed and synthesised to support content development. The most notable approaches include machine learning and crop modelling, although less sophisticated approaches, such as statistical analysis and qualitative interpretation, are also used frequently. The availability of analysis software and scalable cloud services to process sensor data and enable management and analysis of large datasets are key enablers for DDAS start-ups.

Advances in **machine learning** have enabled the analysis of large datasets, such as satellite remote-sensing data, for use in agricultural and other contexts. Machine learning enables computers to learn from 'experience' rather than being explicitly programmed to do specific tasks.[120] It is most suited to the analysis of large, unstructured datasets such as visual data from satellites, data from soil sensors or service usage data. The most common form, supervised machine learning, requires an extensive dataset where both the outcome and independent variables are known. These are used to train the model, which can then be applied to new data. For example, for machine learning to identify crop types from satellite images, a dataset of already-labelled images is required to develop the algorithm. This is the main limitation to machine learning approaches in development contexts, as the ground-level verification data required to train machine learning models is often not available and must be manually collected through primary data collection such as surveys, crowdsourcing, citizen science and other approaches. Applications of machine learning include identifying crops from satellite images, diagnosing diseases based on plant images and creating global soil maps to predict soil properties in areas where soil testing data is not available.[121]

Modelling approaches use numerical representations of cropping systems to understand how the interaction of specific variables, such as crop type, soil nutrient content or water availability, influence an outcome of interest, such as crop yield, pest and disease incidence and emissions produced. Modelling is most suited to predict the outcome of a combination of variables, based on either actual conditions or hypothetical scenarios. In crop modelling, where the main objective is to understand how to optimise cropping practices to maximise yields, the key variables are crop genetic potential, the physical environment and crop management inputs, which are quantified to predict crop growth.[122] This approach enables a better understanding of many agricultural phenomena, including yield gaps, pest and disease outbreaks and ideal planting dates.[123]

Recent research has examined how crop modelling can support adaptation through the design of resilient and sustainable crop production systems in a changing climate.[124] Other models[125] quantify emissions from agricultural systems to identify what is driving emissions and alternative practices to reduce emissions, which contribute to climate change mitigation. A range of models specialise in specific crops or outcomes. They are typically developed by universities and research institutes and are openly available.[126] The main limitations to modelling approaches are the availability and specificity of models to predict local phenomena, as well as the expertise required to use them for analysis.

Due to the computing requirements required by IoT and machine learning approaches, software and cloud services play an important role in providing and enabling analysis. Raw data from IoT, hand-held or UAV sensors is typically processed into usable agricultural data by purpose-built software packages.[127]

120 Brown, S. (2021). Machine learning, explained.
121 Benos, L. et al. (2021). Machine Learning in Agriculture: A Comprehensive Updated Review.
122 Reynolds, M. et al. (2018). Role of Modelling in International Crop Research: Overview and Some Case Studies.
123 Ibid.
124 Peng, B. et al. (2020). Towards a multiscale crop modelling framework for climate change adaptation assessment.
125 For example, DayCent and DNDC.
126 For example, the Decision Support System for Agrotechnology Transfer (DSSAT) and the Agricultural Production Systems sIMulator (APSIM).
127 For example, Sentera and Dronedeploy.

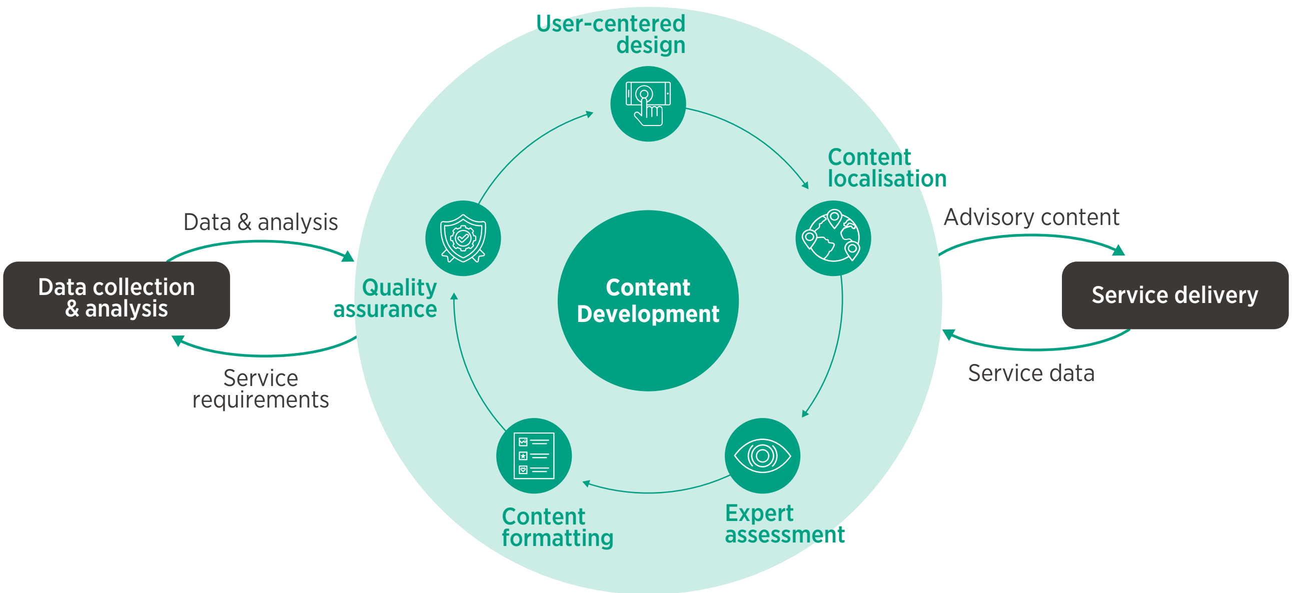
This enables off-the-shelf implementation of sensors to provide standardised measurements and recommendations. Cloud computing services for data aggregation and analysis, as well as service development and hosting,[128] provide scalable environments that enable services to be developed without the need to invest in computing hardware. Microsoft FarmBeats[129] provides a cloud computing environment tailored to the development of data-driven agriculture solutions.

3.1.3 Content development

The content development process ideally commences at the start of service creation when user-centred design (UCD) is used to understand users' information needs and requirements in terms of advisory content and format. It is a reflective process that collects and analyses relevant data, localises content by geographic division, and conducts an expert assessment of the data for each division. This process establishes the most appropriate advisory, formats advice to the appropriate delivery channel and user requirements and has a trusted third-party vet the quality of the advice. As illustrated in Figure 8, this step interacts with the preceding and succeeding steps by filtering, interpreting and formatting the content from data collection and analysis, and monitoring service usage data to identify weak points and measure impact.

Figure 8

Cycle of content development and interaction with service creation steps



Source: GSMA AgriTech

128 For example, Amazon Web Services, Google Cloud and Microsoft Azure.
129 Azure FarmBeats.

Content development covers a range of activities that develop relevant and actionable advisory messages based on the results of data analysis, and deliver these messages to users. User-centred design (UCD), initiated at the start of the service creation process, enables service providers to develop a deep understanding of their target users and their ecosystem to design services that meet their needs and challenges.[130] UCD puts farmers and their experience at the centre of product and service design, and is grounded in continuous and structured interaction with end users. This approach also enables an understanding of the unique needs of marginalised user groups, such as women, farmers with no or low literacy skills and those with disabilities, where these groups are adequately represented in UCD activities and relevant social dynamics are dealt with appropriately.[131] User-centred design should answer three key questions: Which advice should be provided, to whom, and how it should be delivered.

The provision of DDAS requires knowledge of and tailoring content to the contexts of users, most importantly where they are located. Typical approaches to localisation used by DCAS include administrative subdivisions such as Local Government Areas (LGAs) in Nigeria or Districts in Kenya, which range from several hundred to several thousand square kilometres. Government extension agencies often use this approach, which facilitates the development of content for local branches. Within these areas, differentiation will be made to account for variations in agroclimatic zones, such as highland and lowland areas. The availability of GPS coordinates and high-resolution advisory data enables advice to be localised to the farm level with PA services, narrowing the area of interest to several thousand square metres. This has significant implications since weather, terrain and soil composition can vary significantly within administrative areas, making advisory for an entire area only accurate for some farmers. Even within fields, soil composition may change and variations in terrain can have an impact on soil moisture availability. PA services can identify such differences and advise on practices to optimise yields across the farm. Further contextualisation of advice can be done based on other dimensions, such as crops grown and socio-economic characteristics.

Outputs from data analyses typically undergo expert assessment, during which results are synthesised and compared to formulate advisory messaging specific to targeted locations. For example, remote-sensing data showing crop health may be combined with 10-day weather forecasts, soil maps and socio-economic data to produce advice on the quantity and composition of fertilisers to apply, as well as optimal timing and methods. This step may be performed by agronomists employed by the service provider or in collaboration with public or private agricultural research institutes.

Based on the expert assessment, content formatting tailors the advisory content to the delivery channels and targeted user audiences. Possible formats include short text messages, audio and video content, graphics and visualisations or decision trees for chatbots or IVR menus, and may require translation into one or more local languages. Metrics are crucial to maximise the impact of the content, user experience (UX) design[132] and business intelligence.133 UX design is a subset of user-centred design that identifies the most effective ways to present information to users through methods such as A/B testing.134 Business intelligence metrics provide information on the use of digital services and can be used to identify problem areas, such as content that is underutilised by users.

Assuring the quality of advisory messages is key to ensuring impact and adoption of DDAS. Quality assurance measures should be applied throughout the service development process. The development process itself should follow established good practices such as user-centred design[135] and principles of digital development.[136] Data management, especially when applied to farmers' private data, should be in line with best practices[137] to ensure privacy and trust in the service. Input data, such as weather forecasts or soil maps, should be selected based on evidence that they are applicable to local contexts, and can be verified using ground observations where such evidence is not available. Content developed by local experts may need to be approved by local agricultural research agencies prior to release, improving trustworthiness and de-risking provision of the content by the private sector. Monitoring, evaluation and learning (MEL) measures should be integrated in service delivery to understand whether the service is achieving the intended impact and to feed into product iteration.[138]

130 GSMA. (2015). mAgri Design Toolkit: User-centered design for mobile agriculture.
131 Ibid.
132 Ibid.
133 Ibid.
134 A/B testing is an experiment in which two or more variants of a service are shown to users at random, and statistical analysis is used to determine which variation performs better for a given goal. See: www.optimizely.com/optimization-glossary/ab-testing/.
135 GSMA. (2015). mAgri Design Toolkit: User-centered design for mobile agriculture.
136 Principles for Digital Development. (n.d.). Business Model Sustainability Toolkit.
137 For example, the GODAN Code of Conduct Toolkit and the CGIAR Responsible Data Guidelines.
138 GSMA. (2015). mAgri Design Toolkit: User-centered design for mobile agriculture.

3.1.4 Service delivery

Service delivery represents the last mile in DDAS service creation and bridges the gap between content developers and farmers. Selecting the appropriate delivery channel during content development is crucial to ensure farmers can access and interact with the services provided. Selection of the delivery channel needs to assess several factors that determine the appropriateness of the channel for a specific user group. These considerations include affordability and access of the relevant technology; the skills, such as (digital) literacy, required to interact with the service; the safety of the delivery channel, whether digital or in person; and the (perceived) relevance of the channel to users.[139] Considering these factors from the perspective of various user segments, based on gender, disability, age and ethnicity, can yield very different outcomes and must be included to ensure services are impactful and inclusive.

Advisory messages can be delivered through a wide variety of channels and approaches. Face-to-face approaches include farm visits by extension workers or group capacity building sessions, such as farmer field schools. Written materials, smartphones or video screenings may be used for troubleshooting and the delivery of advisory messages. Call centres, pre-recorded messages and IVR services provide spoken messages and simple interactive menus that can be accessed using basic phones. SMS and USSD can deliver text-based advisory through basic phones and can enable interactive services using simple menus or chatbots.

The use of smartphones vastly expands the types of information that can be delivered, but it is limited by cost and the technological literacy it requires. Compared with text-based content, smartphones can provide a range of audio-visual content and enable contextualised data collection from farmers through forms, GPS and cameras. Delivery approaches include mobile apps and chatbots that use popular messaging services such as WhatsApp. Online platforms may be used to provide access to data dashboards, but are typically targeted at medium- to large-sized farms or farmer organisations due to the technical requirements.

3.2 Using data to support agricultural decision-making

This section looks at the specific types of advisory that DDAS can provide throughout the cropping cycle, and links them to relevant data sources and analysis approaches (Figure 9).

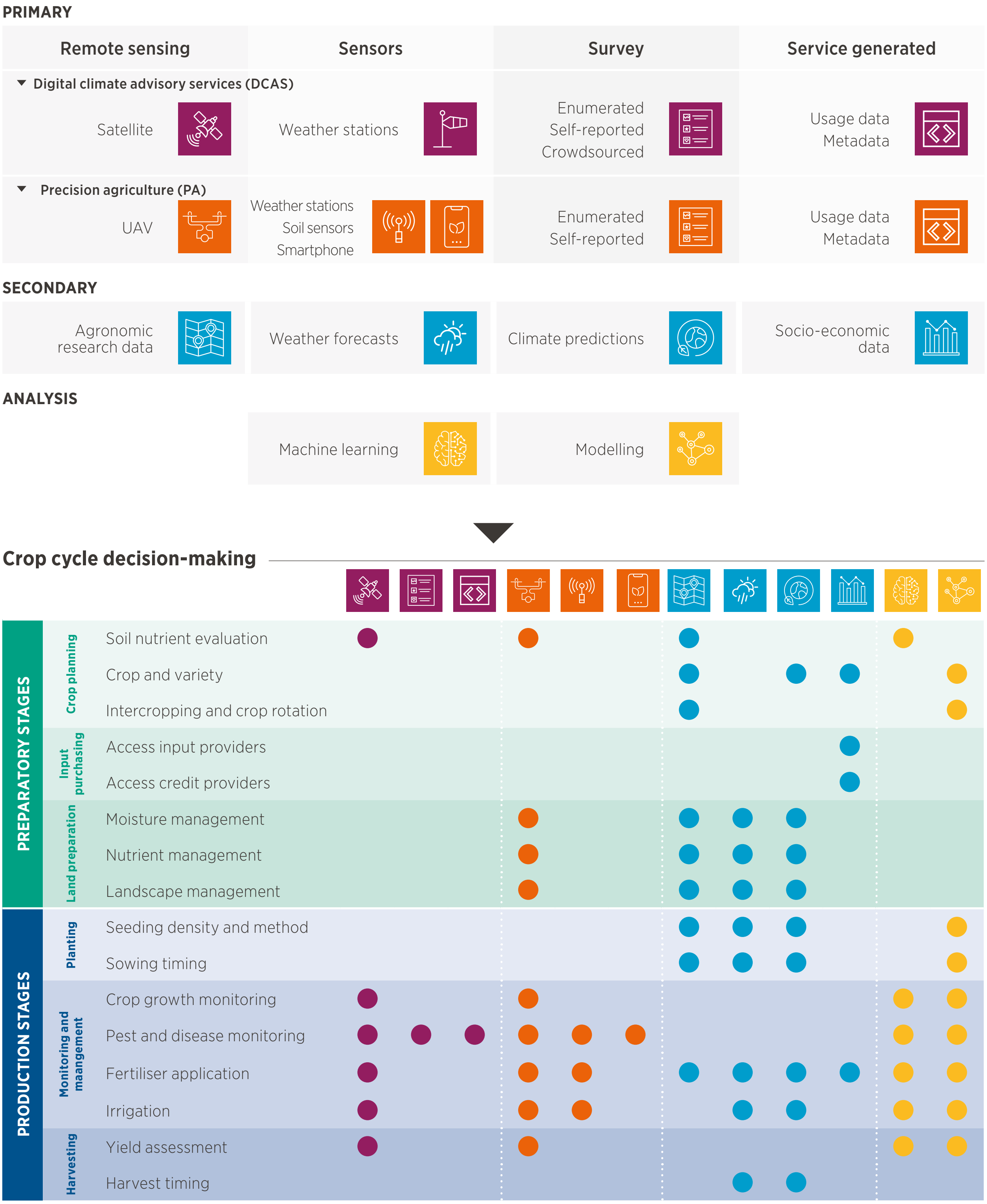
DCAS and PA services targeted at smallholder farmers are distinguished by the resolution of primary data collected to develop the services. DCAS use weather and agricultural data sources localised to administrative subdivisions, such as LGAs in Nigeria or Districts in Kenya. PA uses farm-specific or hyperlocal data that allows services to be customised to the (sub-)farm or field level. While additional factors, such as market access, taste preferences, cultural norms, available resources and access to relevant inputs, will also influence cropping decisions,[140] this section focuses on the use of data to guide agricultural decision-making.

139 GSMA. (2022). Reaching and Empowering Women with Digital Solutions in the Agricultural Last Mile.
140 Bekele, A. S. et al. (2007). Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices.

Figure 9

DDAS-informed decision-making during the cropping cycle[141]

Data sources and analysis approaches



141 Adapted from: Iversen, K. et al. (2021). Frontier Technology Issues: Frontier Technologies for Smallholder Farmers: Addressing Information Asymmetries and Deficiencies.

During the **preparatory stages**, key decisions relate to the choice of crops and varieties, whether to mix crops or apply crop rotations over seasons, how to prepare land for moisture and nutrient management and which inputs are necessary to source. To inform these choices, an assessment must be made of the suitability of land for the cultivation of specific crops and varieties. Soil maps[142] provide data on soil composition while crop suitability maps[143] consider the crop characteristics and their interaction with contextual factors to provide recommendations on the most suitable crops and varieties. Crop modelling[144] and machine learning[145] approaches can be used to quantify trade-offs between crop choices and enable the optimisation of intercropping and crop rotation systems. Seasonal climate forecasts provide an outlook of expected weather trends, including the expected timing and amount of precipitation and expected duration of the cropping season,[146] to tailor decision-making to time-sensitive factors. Combined with content on good agricultural practices, these data sources and crop choices can inform decisions about land preparation to provide the most beneficial environment for the climate outlook, physical environment and crop variety. These decisions will, in turn, inform the identification of required inputs. DDAS can support the sourcing of inputs by providing information on suitable inputs and input providers that are accessible to the users.

PA approaches during the preparatory stages include the use of UAVs and soil testing to provide farm-level data on soil characteristics and support more tailored crop and variety choices and nutrient management decisions. UAVs also provide insight on moisture content across the cultivated area, including dry and potentially waterlogged areas, which will improve the implementation of moisture management approaches.

Activities during the **production stages** put the season's plans into action, monitor and manage crop growth and respond to environmental issues, such as crop pest and disease pressures and adverse weather events. The decision about when to plant will be influenced by seasonal climate forecasts of the expected start and duration of the season, and more detailed 10-day forecasts can optimise activities based on the most favourable conditions.[147] Monitoring of crop pests and disease can be supported by satellite remote sensing, where sufficiently high resolution systems (<5 metres) can sense plant damages caused by diseases and pests.[148] Modelling approaches combined with monitoring of environmental factors, such as weather, drought and moisture stress on crops, enable prediction of pest and disease risks.[149] The timing of fertiliser application will largely be determined by daily or 10-day weather forecasts to avoid washing out by rainfall.[150] Fertiliser composition and rates can be informed by soil maps and crop models that provide details on available and required nutrients, respectively. Similarly, irrigation practices will be mainly informed by 10-day weather forecasts to optimise water use, while remote-sensing data can be used to estimate evapotranspiration rates and determine crop moisture requirements.[151]

PA approaches during the cropping stage enable a wider range of advisories than reliance on local data sources alone. The use of UAVs enables periodic, high-resolution monitoring of a cultivated area, allowing problem areas in the crop to be identified related to a lack of nutrients,[152] water availability[153] and pest and disease issues.[154] Soil sensors can further improve irrigation practices by providing real-time observations of soil moisture content. Smartphones can be used to diagnose crop pests and diseases using computer vision analysis of images of affected plants[155] and enable targeted treatments.

142 Miller, M.A.E. et al. (2021). iSDAsoil: The first continent-scale soil property map at 30 m resolution provides a soil information revolution for Africa.
143 Peter, B.G. et al. (2020). Crop climate suitability mapping on the cloud: a geovisualisation application for sustainable agriculture.
144 Reynolds, M. et al. (2018). Role of Modelling in International Crop Research: Overview and Some Case Studies.
145 Benos, L. et al. (2021). Machine Learning in Agriculture: A Comprehensive Updated Review.
146 Born, L. et al. (2021). A global meta-analysis of climate services and decision-making in agriculture.
147 Ibid.
148 Zhang, J. et al. (2019). Monitoring plant diseases and pests through remote sensing technology: A review.
149 Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT). (2020). Data-driven solutions for Africa: using smart tools to combat climate change.
150 Born, L. et al. (2021). A global meta-analysis of climate services and decision-making in agriculture.
151 Sishodia, R.P. (2020). Applications of Remote Sensing in Precision Agriculture: A Review.
152 Yang, X. et al. (2021). Soil Nutrient Estimation and Mapping in Farmland Based on UAV Imaging Spectrometry.
153 Sishodia, R. P. (2020). Applications of Remote Sensing in Precision Agriculture: A Review.
154 Zhang, J. et al. (2019). Monitoring plant diseases and pests through remote sensing technology: A review.
155 Plantix.

3.3 Opportunities for data-driven advisory services to inform climate-smart agriculture practices

Based on the identification of widely applicable CSA practices in chapter 2 and DDAS decision-making support in the previous section, this section synthesises these findings to identify where DDAS can inform the application of CSA practices by smallholder farmers.

Table 3 presents, in descending order, the expected potential of DDAS to inform the adoption of CSA practices. While crop rotation was previously included as one of the components of conservation agriculture (CA), it is treated separately here, as it is implemented as a stand-alone practice and has more specific DDAS requirements than the combined set of practices that constitute CA.

DDAS that support decisions about which crops and crop varieties to grow, have the greatest potential to enable a variety of CSA practices. The choice of crop has a direct influence on the stress tolerance of the crop and influences water and nutrient management approaches. Decision-making support with crop choice in intercropping systems can enable and optimise the implementation of intercropping and crop rotation systems. Fertiliser application planning based on soil data can optimise fertiliser composition and quantity and enable the choice of appropriate organic inputs. Weather and climate forecasts optimise agricultural practices by enabling the right timing of planting, fertiliser application and harvesting, based on expected season duration and precipitation forecasts.

CSA practices expected to benefit the least from DDAS are CA and IPM. For these practices, the identification of input providers can enable access to the mechanisation required by conservation and reduced tillage agriculture, and crop and variety choice is an important factor in IPM. However, these contributions are expected to be relatively small. CA and IPM are multi-dimensional practices that require considerable capacity building to implement and emphasise adopting a new approach to farming, rather than the incremental changes and improvements that the time- and context-sensitive advisory of DDAS can provide.

Table 3

Expected contribution of DDAS to CSA practices

EXPECTED POTENTIAL FOR DDAS TO INFORM CSA PRACTICES

DDAS advisory →	CSA practice	*Contribution*
Fertiliser application planning	Fertiliser management	• *Soil composition data informs fertiliser composition and quantity* • *Weather forecasts enable timing of fertiliser application to maximise uptake and reduce leaching*
Crop & variety choice	Crop tolerance to stress	• *Data on soil composition, crop suitability and climate forecasts enable the choice of crop (varieties) most suited to the current context*
Crop & variety choice	Water management	• *Data on soil composition, crop suitability and climate forecasts enable the choice of crop (varieties) most suited to maximising moisture conditions*
Sowing timing		• *Seasonal weather forecasts inform timing of planting to maximise use of available moisture during season*
Irrigation planning		• *Observations of soil moisture and weather forecasts support efficient irrigation practices*
Crop and variety choice	Intercropping	• *Data on soil composition, crop suitability and climate forecasts enable the choice of crop (varieties) most suited to the current context*
Cropping pattern choice		• *Modelling approaches simulating cropping sequence can inform choice of crops used in mixed system*
Crop and variety choice	Crop rotation	• *Data on soil composition, crop suitability and climate forecasts enable the choice of crop (varieties) most suited to the current context*
Cropping pattern choice		• *Modelling approaches simulating cropping sequence can inform choice of crops used in rotation*
Sowing timing		• *Seasonal forecasts inform timing of planting*
Input providers identification	Organic inputs	• *Identify sources of organic inputs*
Fertiliser application planning		• *Soil composition data informs fertiliser composition and quantity* • *Weather forecast enable timing of fertiliser application to reduce leaching*
Identification of input providers	Conservation agriculture	• *Identify relevant service providers e.g. no-till planters*
Crop and variety choice	Integrated pest management	• *Data on soil composition, crop suitability and climate forecasts enable the choice of crop (varieties) most suited to IPM approach*

Source: GSMA AgriTech

4

Market contexts: India, Kenya and Nigeria

With many factors influencing service creation and the adoption of data-driven advisory services (DDAS) by smallholder farmers, the DDAS landscape varies significantly from country to country. As outlined in chapter 3, DDAS require data from a range of sources and organisations with the necessary skills to collect and analyse this data, develop digital services and interpret the data to create context-specific advisory messages.

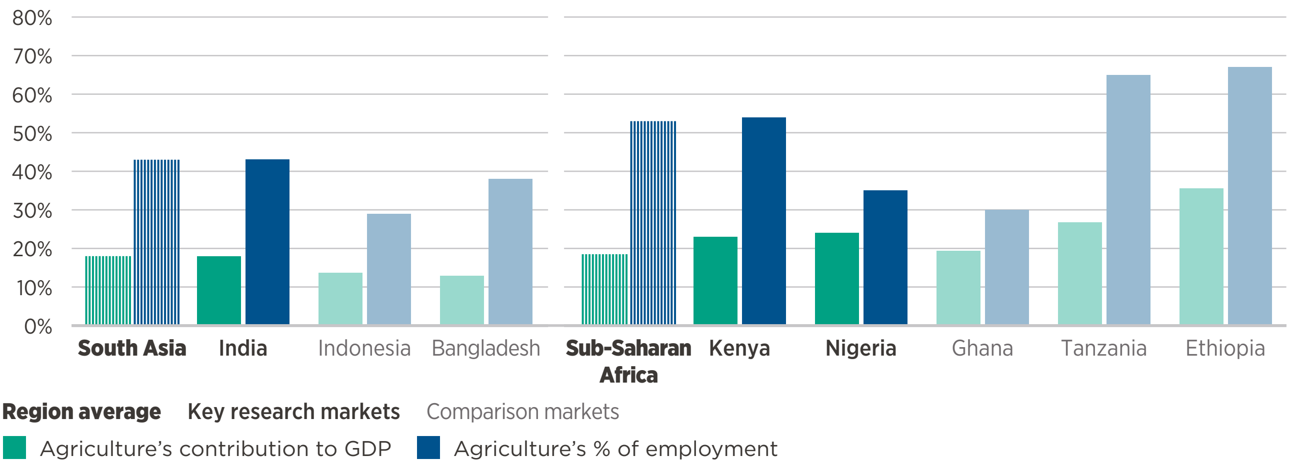
The availability of these components varies across countries, shaping the individual DDAS ecosystems. DDAS are further constrained by the ability to develop sustainable business models, which can depend on the presence of in-country partners, investors and/or government or donor support.

To understand how DDAS are evolving in practice and enabling the adoption of climate-smart agriculture (CSA) practices by smallholder farmers, India, Kenya and Nigeria were chosen as key research markets. All three countries are pioneers in the adoption of agritech innovation and have sophisticated and diverse digital agriculture ecosystems. It is expected that these ecosystems could provide lessons for DDAS and CSA practitioners across low- and middle- income countries (LMICs). This chapter will provide a short introduction to these markets, comparing their agricultural, agritech and climate contexts and those within their wider region. These contexts are expected to have the greatest influence on the development of DDAS.

4.1 Agriculture

Figure 10

Comparison of markets by economic indicators[156]



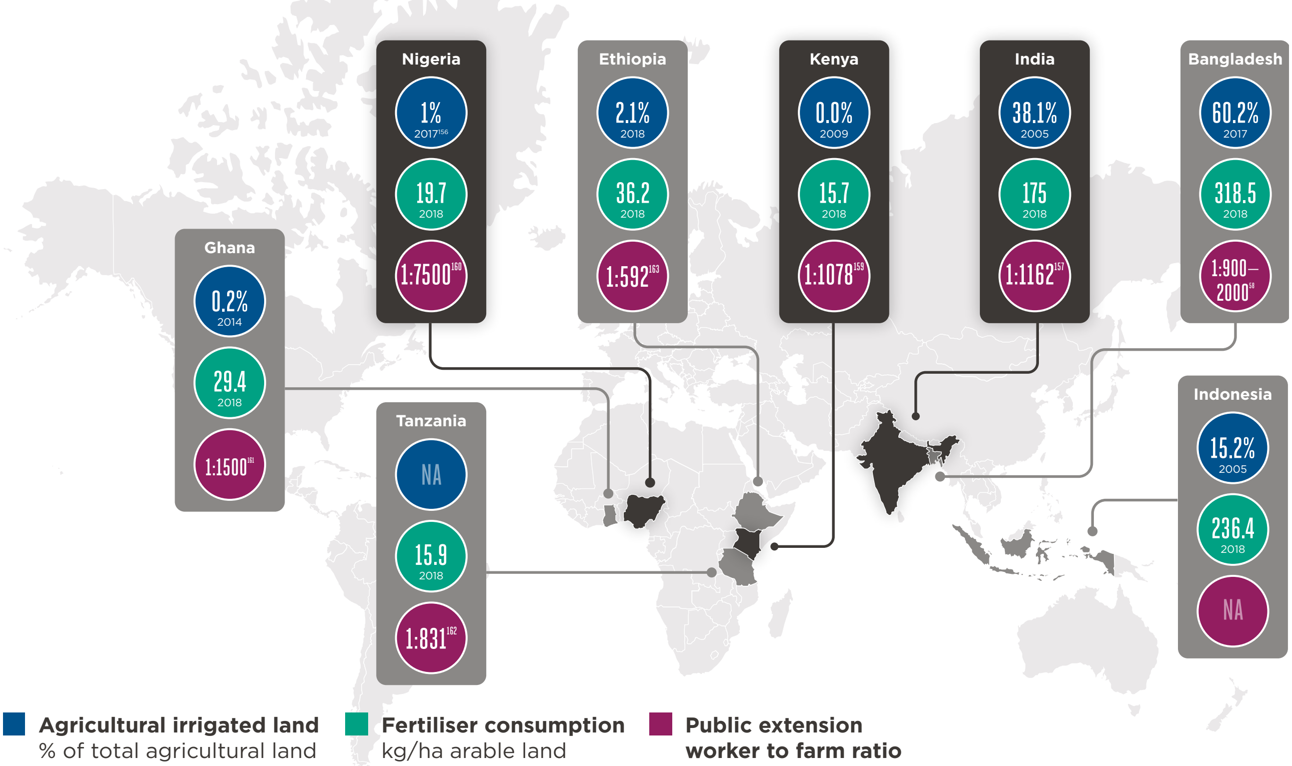
Source: GSMA AgriTech

Agriculture is a key contributor to the economy of each of the focus markets, providing up to a quarter of GDP in Nigeria. As the most industrialised nation of the three, agriculture's contribution to GDP is lowest in India, although still significant at almost one-fifth. In terms of employment, agriculture contributes to more than half of total employment in Kenya, and in Nigeria and India, well over one-third of the workforce are employed in agricultural activities. The role of agriculture in India is more important than in other large markets in South Asia, such as Indonesia and Bangladesh where it plays a smaller role in the economy. Kenya and Nigeria both rely more on agriculture for income compared to the average for Sub-Saharan Africa, although there is wide variation across countries in the region. Employment shows similar variation across Sub-Saharan African countries, with Kenya slightly above average and Nigeria clearly on the next page.

156 Unless indicated otherwise, statistics relate to 2020 and were sourced from World Bank Open Data.

Figure 11

Comparison of markets by agriculture-related indicators[157]



Source: GSMA AgriTech

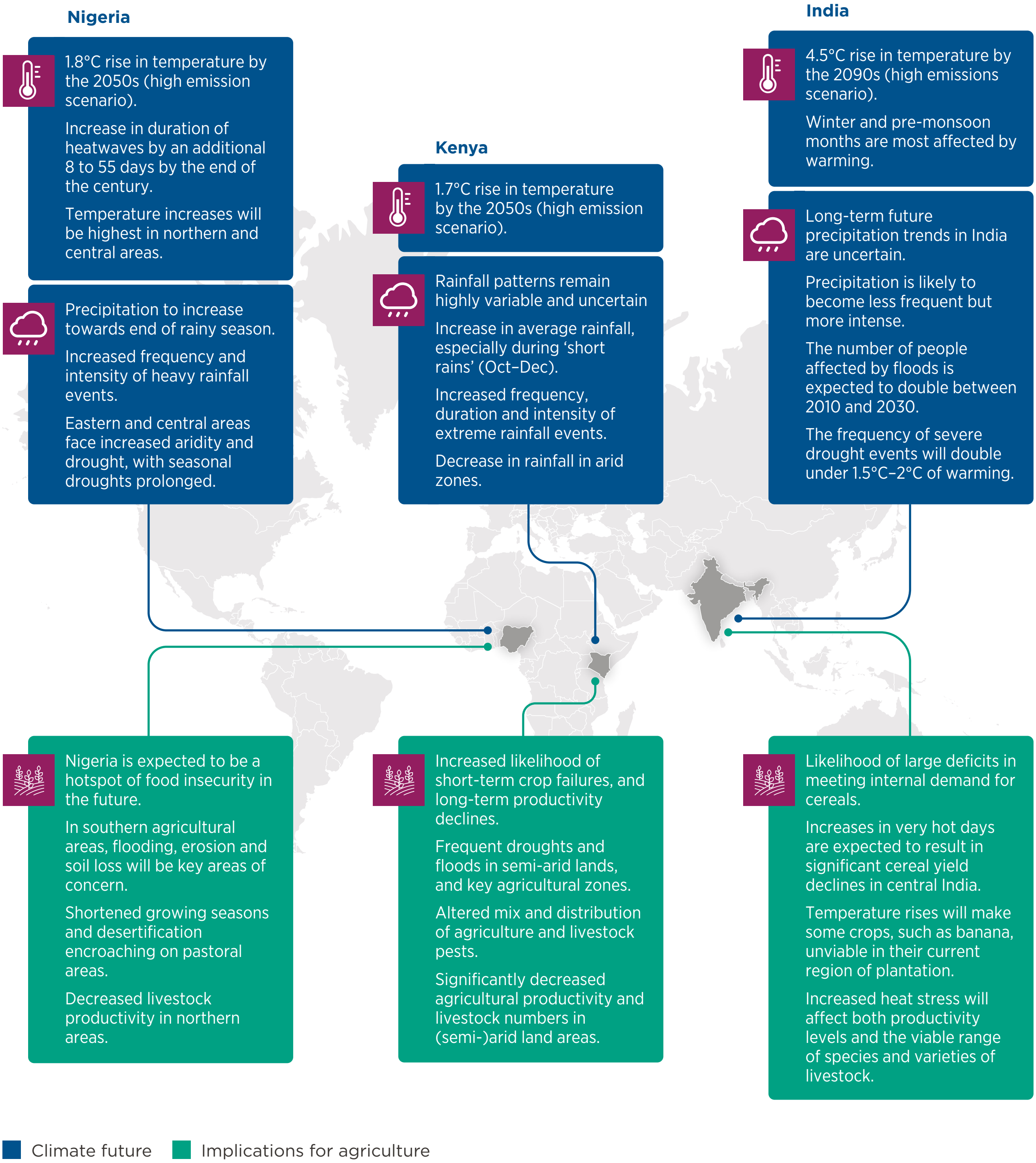
Agricultural production in all countries is predominantly rainfed. However, state subsidies to use electricity for groundwater pumping or solar irrigation systems in India have led to high levels of irrigation in areas with low rainfall but high availability of groundwater or perennial rivers.[166] While recent initiatives provide a similar public stimulus to irrigation in Kenya,[167] and the need for irrigation is recognised in Nigeria,[168] both countries have much lower levels of irrigation, in line with other countries in West and East Africa. Fertiliser use in India benefits from a national scheme that subsidises the sale of fertiliser to farmers.[169] Poor information on nutrient requirements and subsidy-driven, imbalanced application of fertiliser is a major problem in India and South Asia more broadly, leading to significant environmental problems.[170] Public input subsidy programmes in Kenya have not been as effective as their Indian counterparts, but efforts are being made to restructure existing schemes, including investments in domestic fertiliser production.[171] Efforts in Nigeria to stimulate fertiliser use under the Presidential Fertiliser Initiative[172] faced challenges related to production and distribution, undermining its impact. While extension services in India and Kenya are at similar levels, and in line with other markets in the regions, the extension worker to household ratio in Nigeria is almost seven times lower. Extension services in each of the countries are covered in more detail in section 4.3.

157 Ibid.
158 Xie, H. et al. (2017). Invest in small-scale irrigated agriculture: A national assessment on potential to expand small-scale irrigation in Nigeria.
159 Nandi, R. and Neduraman, S. (2019). Agriculture Extension System in India: A Meta-analysis.
160 Feed the Future. (2017). Bangladesh: Desk Study of Extension and Advisory Services.
161 The African Seed Access Index (TASAI) Dashboard.
162 Ibid.
163 Ibid.
164 Ibid.
165 Ibid.
166 Dhawan, V. (2017). Water and Agriculture in India: Background Paper for the South Asia Expert Panel During the Global Forum for Food and Agriculture (GFFA).
167 National Irrigation Authority, Kenya.
168 Malabo Montpellier Panel. (2018). Water-Wise: Smart Irrigation Strategies for Africa: Nigeria.
169 Government of India: Department of Fertilizers.
170 Kishore, A. et al. (2021). Development of balanced nutrient management innovations in South Asia: Perspectives from Bangladesh, India, Nepal, and Sri Lanka.
171 Boulanger, P. et al. (2020). Effectiveness of fertilizer policy reforms to enhance food security in Kenya: a macro-micro simulation analysis.
172 Federal Ministry of Agriculture and Rural Development (FMARD), Kenya.

4.2 Climate challenges

Figure 12

Projected climate futures and implications for agriculture[173]



Source: World Bank Climate Risk Country Profiles

173 Climate Risk Country Profiles: https://climateknowledgeportal.worldbank.org/country-profiles

Climate change is posing additional challenges to agriculture in all three markets, with climatic trends having severe implications for crop production (Figure 12). A warming climate is resulting in changing weather patterns in all three countries, where seasonality is becoming less predictable, dry areas are expanding and extreme weather events such as droughts and heavy rainfall are becoming more frequent and intense. In Nigeria, annual flooding in many states, especially in the South-West of the country, is one of the top factors influencing food security.[174] In October 2020, torrential rainfall, river floods and flash floods washed away wide swathes of farmlands causing crop losses and localised production shortfalls.[175] In 2020, northern Kenya suffered its worst desert locust invasion in 70 years,[176] driven by unusually heavy rainfall in their breeding grounds on the Arabian peninsula and Horn of Africa.[177] The resulting invasion put the food security of almost three million vulnerable households at risk.[178] In India, a slower moving challenge of soil degradation due to salinisation, alkalisation, water logging and wind erosion that is estimated to affect up to 32 per cent of the country's area is exacerbated by climate-related issues such as dryland expansion and desertification.[179]

Several CSA practices have been identified that can mitigate the impact of these and other climate stresses on agricultural productivity. According to assessments by the World Bank[180] and FAO,[181] the highest impact CSA practices in both Kenya and Nigeria include improved and drought-resistant seeds for staple crops, integrating trees in agricultural systems through alley cropping or agroforestry, as well as intercropping. Measures to deal with flooding in Nigeria include terracing of farmlands to reduce erosion and collect run-off water for farming activities. Dealing with desert locusts in Kenya included continuous surveillance of swarms using ground, air and human methods combined with targeted spraying of swarms.[182] Strategies to deal with soil degradation in India include controlling erosion and harvesting water by, for example, bunding or terracing, managing nutrients through intercropping or crop rotation and conservation agriculture.[183]

174 Echendu, A. J. (2022). Flooding, Food Security and the Sustainable Development Goals in Nigeria: An Assemblage and Systems Thinking Approach.
175 World Food Programme. (2021). Global Report on Food Crises.
176 The World Bank. (2020). FAQs – Kenya Locust Response Project.
177 FAO Locust watch.
178 World Bank. (2020). FAQs – Kenya Locust Response Project.
179 World Bank. (2021). Climate Risk Country Profile: India.
180 World Bank and CIAT. (2015). Climate-Smart Agriculture in Kenya.
181 FAO, ICRISAT, CIAT and CCAFS. (2019). Climate-Smart Agriculture in the Adamawa State of Nigeria; FAO, ICRISAT, CIAT and CCAFS. (2019). Climate-Smart Agriculture in the Borno State of Nigeria; FAO, ICRISAT, CIAT and CCAFS. (2019). Climate-Smart Agriculture in the Yobe State of Nigeria.
182 FAO. (2021). Desert Locust Upsurge: Progress report on the response in the Greater Horn of Africa and Yemen.
183 Bhattacharyya, R. et al. (2015). Soil Degradation in India: Challenges and Potential Solutions.

4.3 Agricultural research and extension

Agricultural research and extension services play a vital role in agricultural and rural development. They address challenges of agricultural productivity by conducting research and trialling improved seed varieties, approaches to pest and disease management, soil and water management and many other areas.

Ultimately, this contributes to the formulation of good agricultural practices (GAPs) that can be disseminated to farmers through extension networks. This body of research can be a key input for DDAS, providing the necessary advice to address challenges on the ground. Research and extension services can also serve as developers and distributors of climate-smart agricultural practices, and delivery bodies for government subsidies and inputs.

In Nigeria, the state-based network of agricultural development programmes (ADPs) initiated by the World Bank currently suffer from a lack of funding with little or no allocation from state governments.[184] The agricultural research system is similarly extensive but underfunded, consisting of commodity-based research institutes, agricultural universities and university departments and an international agricultural research centre.[185] This lack of funding is evident in the ratio of extension workers to farmers, which is approximately seven times less than that of Kenya, India and other markets in Sub-Saharan Africa. Agrometeorological forecasts are provided by the Nigerian Meteorological Agency (NIMET).[186] Few private weather services providers were found in Nigeria. Ignitia[187] is a notable exception, which may be related to the regulations stipulating that weather services in Nigeria must always be provided in collaboration with NIMET.

Historically, the Kenyan government has provided extension services to both small-scale farmers and commercial producers. However, during the 1990s, pressure to reduce government influence on the agriculture sector reduced the extension budget and extension staff numbers.188 Private sector and non-profit approaches to extension have moved in to fill the gaps left by the public extension system, forming the current complex extension landscape. Kenya has a variety of agricultural research institutions, including the public Kenya Agricultural and Livestock Research Organisation (KALRO), several international research institutes operating under the CGIAR partnership, commodity-based associations, as well as numerous universities with agriculture departments. Weather services in Kenya are provided by the Kenya Meteorological Department (KMD), with private providers such as Weather Impact, and the no-longer operational aWhere, which are also involved in services across the country.

Agricultural extension services in India are dominated by the public sector and led by the Indian Council of Agriculture Research (ICAR), with efforts coordinated by district-level Agriculture Technology Management Agency (ATMA) societies. Other public agricultural research organisations include field research units of ICAR, state agricultural universities and government-led information and communications technology (ICT) interventions.[189] The agricultural extension landscape is diversified by private-sector services, mostly delivered by input dealers,[190] and non-governmental organisation (NGO) activities.[191] India has seen the growth of farmer producer organisations (FPOs)[192] since 2013, which often provide their members with extension knowledge. The India Meteorological Department is the public weather forecaster and provides their Agromet Field Units with district-specific weather forecasts twice weekly.[193] Private-sector involvement in agromet services includes weather observation, forecasting and dissemination by commercial and non-profit organisations such as Skymet,[194] the Watershed Organisation Trust[195] and CropIn.[196]

184 Auta, S.J. and Dafwang, I.I. (2010). The Agricultural Development Projects (ADPs) in Nigeria: status and policy implications.
185 Feed the Future. (2017). Nigeria: In-depth Assessment of Extension and Advisory Services.
186 Nigerian Meteorological Agency.
187 Ignitia.
188 Global Forum for Rural Advisory Services (GFRAS).
189 For example, mKisan and the Kisaan Knowledge Management System.
190 For example, IFFCO Kisan.
191 For example, BAIF and Digital Green.
192 The National Association for Farmer Producer Organisations (NAFPO) in India defines a farmer producer organisation as a hybrid between cooperative societies and private limited companies.
193 Centre for Science and Environment. (2020). Agrometeorological Advisory Services in India: An Assessment.
194 www.skymetweather.com
195 https://wotr.org/
196 www.cropin.com

4.4 Digital agriculture

Digital agriculture solutions have matured over the past decade, increasingly reaching sufficient scale to become commercially attractive to investors while also having a positive socio-economic impact on smallholder farmers.

These solutions are divided into five use cases: Digital advisory and agri digital financial services (access to services), agri e-commerce and digital procurement (access to markets) and smart farming (access to assets).[197]

All three markets have seen strong growth in the digital agriculture sector and innovative use cases. GSMA research has shown that Kenya is home to the most innovation among LMICs with 95 active digital agriculture services in 2020, followed by India (68 in 2020) and Nigeria (47 in 2020).[198] Innovation in artificial intelligence (AI) tells a similar story, with India, Kenya and Nigeria leading LMICs in activity, with 180 AI use cases addressed by start-ups in India in 2020.[199] This innovation is enabled, in part, by relatively extensive digital infrastructure and high mobile adoption rates, both of which are required for service creation and delivery.

In terms of investment in agritechs, Kenya and Nigeria represented more than 96 per cent of agritech funding in Sub-Saharan Africa in 2021 ($68 million and $23 million, respectively),[200] while investment in farm tech start-ups in India totalled $527 million. In Nigeria, agritech is the smallest sector of investment, accounting for only 2.6 per cent of total investment. Funding across tech start-ups is focused on pre-seed and seed stages, indicating a high level of activity with low levels of maturity. Conversely, investment in agritech in Kenya is second only to investment in AI, which accounts for 23.4 per cent of total funding. The maturity of agritechs in the Kenyan ecosystem is also more balanced, with a mix of late- and early-stage companies. India's tech start-up sector is expanding rapidly, ranking third globally in 2021 after the US and China, with agrifood start-ups accounting for approximately five per cent of total funding. In this established market there is a mix of early- and late-stage companies.

In terms of the most funded use cases, value chain digitisation solutions are successful in all markets, with DeHaat India closing their largest funding round in 2021 ($115 million).[201] Apollo Agriculture raised one of the highest rounds of agritech funding in Kenya in 2022 ($40 million),[202] while Nigerian Thrive Agric is one of the most successful start-ups in Nigeria, raising over $56.4 million in finance in 2022.[203] In 2021 commodity-specific value chain development organisations Agricorp (ginger) and Releaf (palm oil) won the largest proportion of funding in Nigeria. Agri e-commerce platforms are also successful across markets, with Kenya's Twiga Foods raising series C funding in 2021, and Vendease, a B2B e-commerce platform, raising the second highest level of funding in Nigeria. In India, agribusiness marketplaces raised almost three times the amount of funding in 2021 compared to 2020.

The following two chapters will present the landscape of DDAS solutions in Nigeria, Kenya and India, by DDAS use case. Following the service creation framework presented in chapter 3, chapters 5 and 6 will aim to characterise approaches to DDAS provision, highlighting key activities in service creation, as well as differing approaches to business models that enable service creation and sustainability. Digital climate advisory services (DCAS) will be covered in chapter 5 while precision agriculture (PA) will be covered in chapter 6.

197 GSMA. (2020). Digital Agriculture Maps.
198 Ibid.
199 GSMA. (2020). Artificial Intelligence and Start-Ups in Low- and Middle-Income Countries: Progress, Promises and Perils.
200 Disrupt Africa. (2021). The African Tech Startups Funding Report.
201 Singh, M. (2021). DeHaat raises $115 million in the largest agritech round in India.
202 Apollo Agriculture on Crunchbase.
203 Thrive Agric on Crunchbase.

5
Digital climate advisory services for agriculture

Digital climate advisory services (DCAS) provide information on agronomic best practices, pests and diseases and weather and market prices to smallholder farmers through digital channels. They draw on weather and climate forecasts, as well as agronomic data such as soil maps, to tailor advisory messages to local and seasonal conditions.

The DCAS approach to localisation ranges from several hundred to several thousand square kilometres in area. These services enable smallholder farmers to reduce costs and maximise their agricultural production and revenues by selecting the most appropriate inputs, optimising agricultural practices and responding to crop pests, disease and extreme weather events in a timely and effective manner. This chapter presents the current landscape of DCAS across the three target markets, providing an overview of current service providers, the business models used to enable such services and an analysis of the key contributors to service creation.

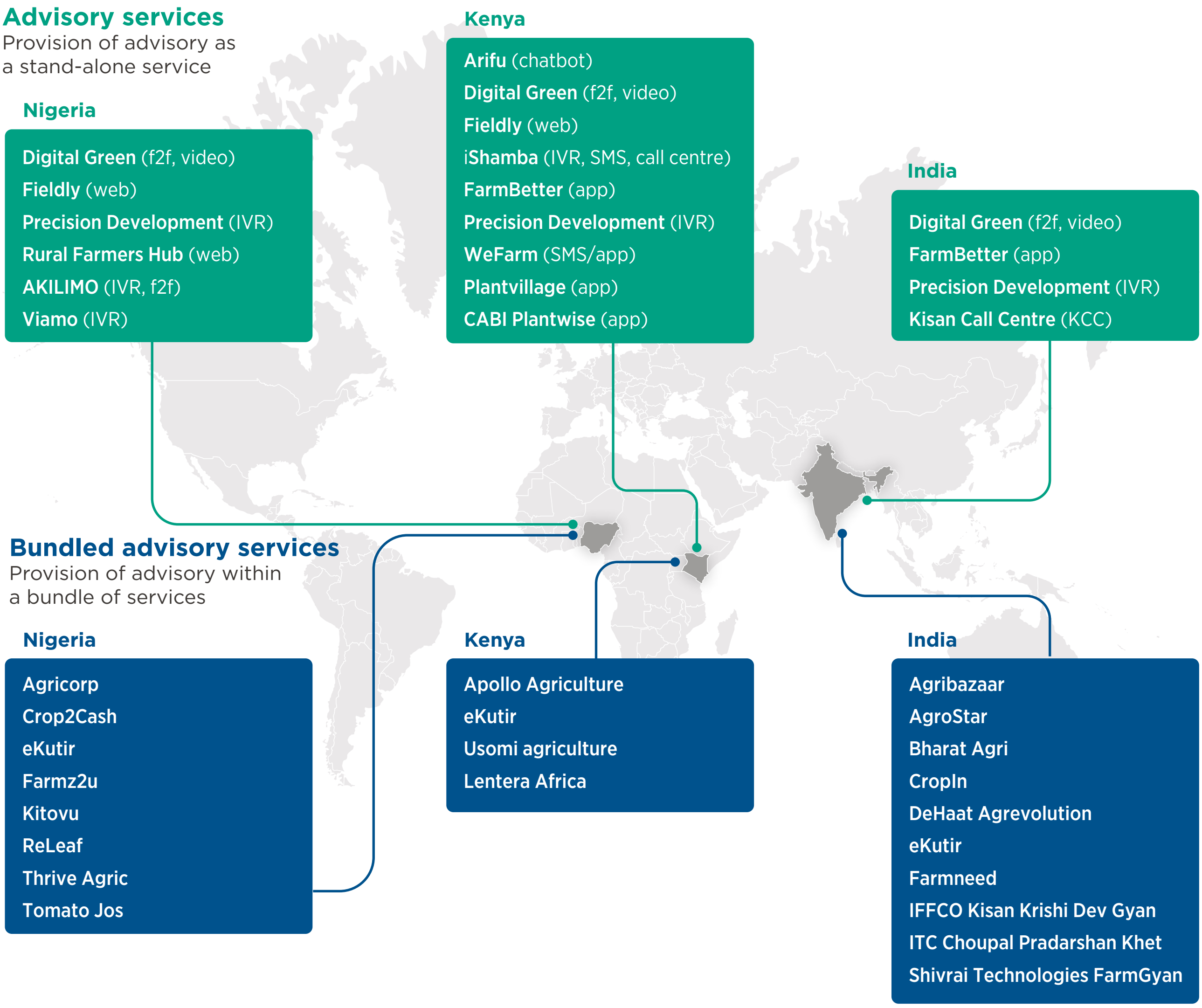
5.1 Landscaping services in India, Nigeria and Kenya

An assessment of DCAS providers across the target markets (Figure 13) reveals a distinction between those that provide advisory services as a stand-alone service, and those that offer advisory as part of a bundle of services, typically aimed at digitising value chain activities such as access to inputs, credit and output markets.

While these approaches share the core service creation steps, their underlying business models, including partnerships, and revenue generation, differ significantly. The following sections will discuss these differences in more detail.

Figure 13

Landscaping of DCAS providers in the target markets



Source: GSMA AgriTech

Of the three markets, India shows the most activity in DCAS. Many providers are capitalising on the fragmented but thriving agriculture ecosystem in India to serve farmers with DCAS as a part of bundled services that connect them to banks, seed companies and input providers in their area. Including DeHaat and IFFCO Kisan, DCAS providers typically work with the extensive ICAR network for content development, effectively functioning as an additional, digitised arm of the public extension system with agents on the ground that register farmers and deliver services. Several established public and donor-funded services, such as KCC, Digital Green and Precision Development, provide advisory-only services through several delivery channels, with each provider specialising in a specific approach or channel.

Kenya is also home to an active DCAS innovation space, characterised by public and donor-funded services that typically target the high number of Kenyan farmers operating outside the major commercial value chains. For example, services provided by organisations such as Mediae (iShamba) or Arifu are collaborations between public, private and non-governmental organisation (NGO) actors that focus on innovations in service delivery that make content engaging and accessible to lower income farmers and marginalised groups. Extensive investment through programmes such as KCSAP[204] to build the capacity of agricultural ecosystem actors is creating the content and partners needed for DCAS providers to develop services. In recent years, the private sector has also seen significant activity, with Apollo Agriculture dominating the value chain digitisation space and providing DCAS as part of their bundled services.

Nigeria hosts a mix of public, donor-funded and private activities, but the market does not yet have the same level of maturity and scale as India or Kenya. The exception is Thrive Agric, which provides financing and value chain digitisation services, including DCAS. Other private-sector players securing significant investment include Tomato Jos, ReLeaf and Agricorp, which focus on digitising the supply chain activities of single cash crops and are starting to introduce advisory. The focus of these organisations – crop aggregation, processing and sales/marketing – indicate that the agribusiness ecosystem is currently not mature enough for those active in value chain digitisation to offer marketplaces for existing services as in India. In the creation of DCAS in Nigeria, there is also less collaboration between digital service providers and the country's agriculture research institutes, indicating a lack of local content on good agricultural practices and climate-smart agriculture (CSA) that DCAS in India and Kenya depend on for content development.

5.2 Business models

To provide advisory services to smallholder farmers sustainably, several factors must be considered.

According to our research, the main factors found to differentiate the business models of DCAS providers were service ownership, key partnerships and the revenue models used to finance service provision. How these are leveraged to provide DCAS to farmers differ significantly between advisory-only and bundled DCAS providers. Common across DCAS, the role of the service owner is to manage the content development cycle, which includes determining user needs, developing localised advisory content and formatting content for delivery. This role may be taken by a different types of organisations. Elements distinguishing advisory-only and bundled advisory services are discussed in more detail in the following sections.

204 Kenya Climate Smart Agriculture Project (KCSAP).

Figure 14

Comparison of DCAS key partners and activities

Data collection and analysis | **Content development** | **Service delivery**

DCAS business model: **Advisory-only services**

Service owner: **Advisory services agritech company**
Also: Agricultural research institutes, media companies

- Applications of user-centred approaches for service design
- Formatting of content for delivery channels
- Delivery of advisory through innovative and inclusive channels

Agricultural research institutes

- Provision of data on agroclimatic zones
- Provision of good agricultural practices
- Expert assessment of data
- Quality assurance of advisory content

Extension services

- Face to face delivery of advisory content

Weather forecasters

- Provision of weather and climate data

Revenue- and financing sources

Governments and donors
- Impact funding

Smallholder farmers
- Subscriptions

Input providers

Agribusinesses
- Advertising
- Data monetisation

DCAS business model: **Bundled services**

Service owner: **Value chain digitisation agritech company**
Also: input providers

- Collecting farm and monitoring data, through field agents, during cropping season
- Development of digital services platform
- Onboarding of partners for bundled service provision
- Development of field agent network for user registration, monitoring and service delivery

Agricultural research institutes

- Provision of data on agroclimatic zones
- Provision of good agricultural practices
- Expert assessment of data
- Quality assurance of advisory content

Weather forecasters

- Provision of weather and climate data

PA providers

- Deployment of precision agriculture (PA) solutions for data collection

Revenue sources

Input providers

Agribusinesses

Mobile operators

Financial service providers

Cross-subsidisation from bundled services, such as:
- Input sales
- Mobile services
- eCommerce platforms
- Crowdfunding
- Produce aggregation
- Financial services

Key: Partner organisation type (• Key activities) | Donors | Customers | Partners for service bundling

5.2.1 Advisory-only services

Agritechs specialising in service delivery platforms typically leverage their expertise to own the content development cycle of advisory-only DCAS.

In advisory-only DCAS, services are typically owned by agritechs that provide advisory services or other organisations specialising in content development, such as agricultural research institutes or media companies. Advisory service providers may specialise in the delivery of content through a specific channel or approach. For example, Digital Green specialises in community video, Viamo in IVR services, Arifu and Farm.Ink in chatbots and Bharat Agri and FarmBetter in mobile apps. These organisations can leverage their expertise and digital infrastructure in content delivery to serve a variety of verticals and user groups. Service owners may come from other private sector organisations, such as in Kenya where the service owner for iShamba is a spin-off from media company Mediae. Mediae produces the popular TV series Shamba Shape Up and recognised the opportunity to leverage their brand to promote a DCAS service through the show. In Nigeria, the International Institute of Tropical Agriculture (IITA), one of the CGIAR agricultural research centres, has developed the Akilimo advisory service, which uses crop modelling to provide bespoke advice to farmers.

Service owners rely on agricultural research institutes and weather forecasters as content partners, and on extension services to support user registration.

Since advisory-only DCAS are typically created by providers that specialise in content development and delivery, their key partners are organisations that can provide the information required for content development. Given their link to donors and government, these most often come in the form of agricultural research institutes that have the capacity to collect and analyse the data required for content development and delivery. Similarly, weather service providers provide crucial data inputs and can come from either the public or private sector. Extension services often provide the link to farming communities and enable the registration of users, either by providing staff that can register farmers for the services in person or databases of user contact details that service owners can use to reach out to offer services.

Advisory-only DCAS typically rely on public and donor funding to provide their services, enabling them to serve non-commercial crops and marginalised groups.

Due to the social value created by advisory services, as well as the difficulty of charging farmers directly for their services, most of the advisory-only DCAS encountered during the research relied on public and/or donor funding to create and operate their services. For example, Precision Development works in partnership with the Nigerian Federal Ministry of Agriculture and Rural Development (FMARD) and the International Fund for Agricultural Development (IFAD) to provide agricultural advisory across eleven states in Nigeria, including conflict-affected and post-conflict states in the North of the country.[205] While iShamba implements a freemium subscription model and provides advertising services through their delivery channels, they also benefit from support from various donor agencies, including USAID. Receiving funding from donors and governments means that services can pursue impact mandates to support food security, empower marginalised groups or champion climate-smart agricultural practices, like iShamba in Kenya. However, reliance on external funding also has implications for service sustainability as services cease to operate when government policies or donor priorities change.

205 Aghadi, C. et al. (23 June 2021). Scaling Advisory Services to Nigerian Farmers in Need. Precision Development Blog.

5.2.2 Bundled services

Service owners use DCAS to enhance the value of their bundled services to farmers.

Service owners of bundled DCAS are typically agritech companies that digitise parts of or the entire agricultural value chain to provide services such as input procurement, advisory services, crop aggregation, procurement and processing. India's DeHaat Agrevolution, for example, provides a fully integrated platform of services, including input procurement and crop sales to farmers, mainly in the eastern states. The provision of advisory services is seen as the foundation of their relationship with farmers and is offered free of charge. Thrive Agric in Nigeria also provides a bundle of solutions, with a strong focus on farmer financing for improved seed and inputs. Under this model, data-driven best practices and market access reduce the financing risk. Apollo Agriculture in Kenya takes a similar approach. IFFCO Kisan, an Indian fertiliser cooperative, works with Bharti Airtel India, a leading MNO, to provide the Green SIM service. In this partnership, IFFCO Kisan uses the advisory services to provide additional value to their members, while the sale of SIM cards through IFFCO Kisan's sales network improves rural penetration and customer loyalty for Airtel.

In addition to agricultural research institutes and weather forecasters as content partners, bundled DCAS providers also partner with precision agriculture (PA) services to customise advice.

To access the considerable data and information sources required to develop DCAS, service owners work with partners that can support data collection and analysis. Local public and NGO research institutes are key partners that can provide advisory content on good agricultural practices most relevant to local conditions. In the absence of the codification, digitisation and publication of knowledge by these organisations, it is extremely challenging for third parties to build the content required to provide services for multiple crops across agroclimatic zones.

In addition, agricultural research institutes can provide the expertise needed to interpret data and formulate advisory messages, and may be required to play a role in quality assurance.

Providers of bundled DCAS operate agent networks that deliver services to farmers and collect farm-level data that enable user segmentation and contribute to further customisation of advisory services.

One of the key activities of bundled DCAS providers is the establishment and management of a network of field agents that fulfil several functions for the DCAS provider, including the profiling of farmers on the platform and the delivery of services to farmers. For example, DeHaat works with a digitally enabled hub-and-spoke logistics model that enables microentrepreneurs to sell inputs and aggregate produce at the last mile. In Nigeria, eKutir works with agribusiness Meadow Foods and local extension agencies to register farmers, sell inputs and procure produce. These networks enable the collection of farmer data that supports further DCAS localisation, but also creates intelligence for the service owner and partners to optimise their operations.

Cross-subsidisation of advisory services from revenue generated by other services in the bundle, typically input sales, enables DCAS to be provided to users for free.

In all bundled DCAS examples, the advisory services complement other, more commercially viable solutions that the service owner is providing to smallholder farmers. As a result, it is commercially viable for service owners to provide DCAS at no direct cost to farmers, cross-subsidising them instead from the revenues of other business activities, typically input sales or produce aggregation. Further synergies are realised from service creation activities that are shared across services, such as digital infrastructure and agent networks, which lower the cost of providing DCAS.

5.3 Service creation

Numerous approaches have emerged to create DCAS. In this section, we will use the framework of steps from section 3.1 (see Figure 5) to evaluate DCAS creation and delivery.

Figure 15 illustrates the activities conducted by DCAS providers in the key research markets. Advisory-only and bundled DCAS services have significant overlap in service creation activities. However, bundled DCAS business models enable data collection and analysis activities not typically conducted by advisory-only DCAS. Those activities or assets found to be key enablers for DCAS are highlighted. Service creation steps are discussed in more detail in the following sections.

Figure 15

DCAS service creation in practice

Data collection

PRIMARY DATA

- Remote sensing
  - Satellite
- **Survey data**
  - **Enumerated (phone)**
  - **Self-reported**
  - **Enumerated (field agents)**
- Service-generated data
  - Usage data
  - Metadata
  - Transactions data
- Sensors
  - Weather stations
  - Soil testing

SECONDARY DATA

- **Agronomic research data**
  - **Agroclimatic zones**
  - Soil maps
- **Advisory content**
  - **Good agricultural practices**
  - Peer-to-peer content
- Weather and climate data

Data analysis

MACHINE LEARNING

- Service usage analysis
- Localising weather forecasts
- Internet of Things (IoT) data analysis

MODELLING

- Crop growth
- Pest and disease

Content development

EXPERT ASSESSMENT

- **Research institutes**
- In-house agronomists

QUALITY ASSURANCE

- Content review committees

CONTENT LOCALISATION

- **Location, crops**
- Agricultural practices
- User segmentation

USER-CENTRED DESIGN

CONTENT FORMATTING

- Outbound
  - Crop cycle advisory
  - Pest and disease early warnings
- Inbound
  - Chatbots
  - Call centre
- Visual
  - Illustrations
  - Video

Service delivery

FACE-TO-FACE

- Extension visits
- Farmer field schools

BASIC PHONES

- Call centres
- IVR
- SMS

SMARTPHONES

- Apps
- Audio-visual content
- Messaging

- **Key service enabler**
- Service creation activities
- Activities enabled by bundled DCAS business models

Source: GSMA AgriTech

5.3.1 Data collection and analysis

Information on agroclimatic zones and good agricultural practices, combined with self-reported user data, form the core of DCAS data collection.

At the core of most DCAS is information on the agroclimatic zones of a given area, including soil types and crop suitability, and existing content on applicable good agricultural practices. These are the starting points for developing advisory content. Self-reported user data captured through digital service delivery channels is used to customise advisory content to the user context. This combination enables advisory content to be tailored to the location of the user, relevant crops and specific point of the cropping cycle.

For example, iShamba in Kenya work with the International Center for Tropical Agriculture (CIAT), which has developed county-specific climate risk profiles (CRPs)[206] with in-depth analysis of climate hazards, their implications across relevant value chains and potential adaptation strategies. This provides a foundation for developing advisory content. Upon registration, advisory content is customised by collecting information on user location (combination of sub-ward and nearest landmarks), and agricultural practices. Before they developed their field-level presence, DeHaat worked closely with local universities and research institutes to build their initial advisory content offering, which has since been further customised using digital and ground-level data sources. In Nigeria, relatively few services were found that demonstrated similar levels of cooperation between research institutes and service providers, indicating limited availability or capacity of research institutes to contribute to DCAS.

Additional sources for advisory content include peer-to-peer sources, as pioneered by WeFarm, where farmers draw on knowledge from their peers using a crowdsourcing model to troubleshoot agricultural problems. While WeFarm is unique in relying almost exclusively on this form of content generation, other, mainly app-based services such as Bharat Agri and the IFFCO Kisan Agriculture App, provide chat-based functionality to enable farmers to share knowledge.

Weather and climate services, although crucial to tailoring content to short-term and seasonal conditions, are infrequently used due to a lack of reliable localised weather forecasts.

Weather and climate data have potential to tailor advisory content to seasonal trends and short-term forecasts, but a lack of reliable forecasts has meant it is not used widely in DCAS. The risk of farmers losing trust in a service due to incorrect climate forecasts is often considered too great. Precision Development is conducting a series of pilots in partnership with a third-party weather forecaster in India and Pakistan to identify whether these forecasts are sufficiently reliable and refine how best to integrate them into their services. The lack of investment in weather observation infrastructure and national meteorological services in the target countries significantly limits the ability of forecasters to localise their forecasts.

Remote-sensing data is frequently used to monitor crop growth throughout the season, identify challenges and customise advice accordingly.

Remote-sensing satellite data is often used as a complementary data source to customise or develop advisory content. Typically, it is used to monitor crop growth throughout the season and to identify the growth stage and problem areas based on NDVI or soil water stress as indicated by evapotranspiration indices. These approaches are implemented by organisations that specialise in remote sensing, such as Fieldy and Rural Farmers Hub, but they are increasingly being adopted by non-specialist service providers, such as IFFCO Kisan, iShamba and Bharat Agri, which either partner with specialist organisations (iShamba) or develop in-house expertise (IFFCO Kisan). In the absence of reliable climate forecasts, Precision Development uses remote-sensing data to understand differences in the timing of the rainy season and adjust the timing of advisory messages.

206 CGIAR and CIAT. (2016–2019). Informing sub-national climate smart agriculture investments in Kenya: county climate risk profiles.

Survey data is the primary source of user registration data, but can also provide data points on farm-level indicators, such as soil fertility.

While survey data is used primarily to collect basic profiling information about users (location, crops grown), it can also be used to provide additional information on field-level conditions and to customise advisory. The Akilimo project in Nigeria has been trialling this approach for their cassava-specific advisory. Using a combination of crop and economic models, they have identified the key data inputs required to develop farm-specific advice. To understand current soil fertility, for example, they developed several reliable proxy questions using field trials. For phone or chat-based services they use farm yields from the previous year, while for face-to-face services they use the size of a typical cassava root stock harvested in the previous season. These methods capture soil fertility more accurately than available soil maps or remote-sensing data.

Data mining service-generated data to identify and predict agricultural challenges has great potential to improve advisory content.

Service-generated data is recognised as having great potential to identify on-the-ground challenges to customise and prioritise advisory content. This typically requires pull-based services where users navigate digital menus (using IVR or USSD) to access the advisory they require, or where queries are captured by call centre staff in a centralised database. The metadata generated by DCAS provides a rich resource for mining trends in requests for information across locations and time, which can indicate the emergence of crop issues such as water stress or the incidence of pests and disease. One of the largest of these datasets, collected and curated by India's Kisan Call Center, spans more than 10 years and includes more than 30 million records. This is currently being explored by various researchers including the digital research initiative of CGIAR to identify the spatio-temporal information demand for the farmers. This type of information could help to uncover early signs of stress or challenges, e.g. rapid detection of pest outbreaks, which may enable the creation of improved predictive models to contain the spread of the event.

Agent networks of bundled DCAS providers enable field-level data collection that significantly increase the accuracy and scope of farm-level data available for service customisation.

The provision of **bundled services** enables additional field-level data collection through field agents or in situ sensors, which, in turn, enables additional and more granular and accurate advisories. For example, the eKutir FarmIT platform collects a total of 375 farm-specific data points by field agents at registration and throughout the growing season. This covers farm data including GPS boundary mapping of fields, historic data on crops grown and yields achieved, soil data based on soil analyses, data on field conditions throughout the season, industry data on the attributes of seeds and fertiliser used and sources where these were purchased. This data feeds into crop models to segment their users and provide better advice on crop choice and nutrient optimisation. While IFFCO Kisan also employ field agents to register farmers and provide services, they are also exploring crowdsourcing data through "digi-walkers" that can provide on-demand, real-time observations through their app.

PA providers are often partners with bundled DCAS providers, making ground-level data from soil tests and automated weather stations available for service creation.

IFFCO Kisan and DeHaat are both working with local partners to enable the use of in situ sensors to collect critical information. Enabling weather observations through AWS is one of the focal areas as these enable the development of accurate, localised weather forecasts that can be used to create weather-responsive advice throughout the season. Capturing soil data is another such area and is enabled through specialist partners as with IFFCO Kisan in India, or the use of soil testing devices by field agents as with eKutir in Nigeria.

Organisations such as DeHaat, Apollo Agriculture or Thrive Agric that offer a bundle of services to farmers, including e-commerce platforms for inputs and outputs, can also use transaction data to capture the use of specific inputs or crop yields and quality that can feed into user segmentation and customised advisory.

5.3.2 Content development and service delivery

The expert assessment by partners, typically agricultural research institutes, plays a key role in interpreting data to develop advisory content.

When translating agricultural data and analysis outputs into advisory messages for smallholder farmers, expert assessment by agricultural research institutes plays an enabling role in interpreting data outputs, identifying appropriate practices and formulating advisory messages that are sensitive to the context of smallholder farmers. All services providing outbound content to farmers covered by this research relied heavily on manual interpretation to develop advisory messages. While some service providers employ in-house agronomists, the content developed by local research institutes remains a key input, and representatives often play a role in quality assurance of the developed advisory content. For example, Precision Development works with in-house agronomists and public research institutes to determine, on a weekly basis, which content to provide through their advisory channels. Prior to dissemination, a content review committee consisting of representatives of agricultural universities and research institutes assesses the proposed messages.

While farm location and crops grown are the minimum data points required for content localisation, additional data on farmer profile and farming practices can help customise it even more.

Content localisation is, at minimum, based on data collected on user location and crops grown, and can be further customised through additional data on farmers' use of inputs and farm practices. These characteristics enable filtering of relevant content and translation into appropriate languages. Additional data on farming practices and household characteristics can enable user segmentation or tailoring of advice based on cost-benefit analyses. For example, the Akilimo service in Nigeria uses a farmer's budget ceiling as an input for their modelling algorithm to determine which investments in seed, fertiliser and mechanisation will produce the highest returns.

Content formatting depends heavily on whether the service is outbound, requiring discrete, time-sensitive pieces of advisory, or inbound, which requires access to content through a navigable menu.

Content formatting is heavily influenced by whether the solution provides outbound and/or inbound services. Outbound services that send regular advice to registered farmers develop content at predetermined intervals and is formatted as one or a series of SMS or recorded audio messages. Inbound services that provide advice on demand, such as call centres, IVR services or chatbots, require a more flexible system for content retrieval. Call centres, such as those operated by IFFCO Kisan or KCC, typically rely on the expertise of agricultural experts, supported with up-to-date contextual information, such as weather conditions and pest and disease pressures, to provide advice. Where it is not possible to provide advice in real time, queries are recorded and answered by agricultural experts that record an answer or select from existing pre-recorded answers. To further support iShamba call centre agents in providing the best advice for callers, CIAT is developing a searchable database based on climate risk profiles and agricultural research. This database will be integrated in the SPROUT platform developed by Mercy Corps AgriFin. A similar approach is being taken by organisations such as Arifu and Learn.ink in the development of chatbots that provide on-demand agricultural content based on decision trees and/or keyword recognition.

The use of user-centred design principles to inform service development varies by type of DCAS, with most attention given to advisory-only services.

User-centred design principles are used by many organisations providing DCAS. At minimum, farmers and other agricultural stakeholders participate in focus groups and surveys, which helps DCAS providers understand service requirements and preferred forms of delivery. Organisations specialising in content delivery, such as Precision Development, Digital Green, Arifu and Viamo, conduct continuous research and testing to understand engagement with the system. This includes analysing metadata on usage patterns and conducting A/B testing on alternative message formats. This user-centric approach also means they are better able to reach marginalised groups, such as women, farmers with low literacy levels or older persons, who typically experience challenges in accessing digital services. Proactive inclusion of these groups in service design and evaluation means that their needs can be recognised, better understood and addressed.

DCAS use a variety of channels to deliver services. Call centres and IVR services remain the most common inbound methods of service delivery, and SMS and recorded audio are the most widely used outbound services. Innovations in the development of chatbots to deliver agricultural advice and training have opened up the use of messaging apps, such as Facebook, WhatsApp and Telegram, which are increasingly being used as smartphones and data become more accessible.

CASE STUDY

iShamba, Kenya

iShamba, a spin-off of Mediae's successful Shamba Shape Up (SSU) TV series, has been providing advisory services to smallholder farmers in Kenya since 2014. Since their inception as a call centre to service the many calls Mediae received out of interest for their TV show, it has evolved into a cross-channel provider of dynamic and localised advisory content.

For content development, iShamba draws on the expertise of several agricultural stakeholders, including CGIAR research centers. One of the CGIAR centers, CIAT uses county-specific climate risk profiles (CRPs)[207] that provide in-depth analysis of climate hazards, their implications across relevant value chains and potential adaptation strategies to develop advisory content.

Developed in collaboration with CIAT and the Kenyan Ministry of Agriculture, Livestock and Fisheries (MALF), CRPs draw on consultations with a range of agricultural stakeholders to ensure climatic, agricultural, socio-economic and institutional contexts are taken into account and lead to the most appropriate solutions for each county.

Dynamic advisory services are enabled through the integration of weather forecasts, seasonal climate predictions and remote-sensing data that the team of agronomists at iShamba use to tailor outgoing advisory messages at the ward level. Specific advisory content has been added to the service in response to acute threats, including locust and fall army worm advisory, as well as content regarding COVID-19.

PARTNERS

Mediae (service owner, media company)

CIAT (research institute)

Safaricom DigiFarm (mobile network operator, MNO)

DATA SOURCES FOR CONTENT DEVELOPMENT

Climate-smart profiles for rural counties (CIAT, MALF, World Bank)

Weather forecasts (aWhere)

Expert assessment (KALRO)

Remote sensing (PlantVillage)

DATA TYPES USED FOR LOCALISATION

Crop / livestock

Location; ward & closest primary school

Recorded during registration to service

DISSEMINATION CHANNELS

DigiFarm platform

Call centre

SMS; Q&A, periodic tips, weather, market prices

Whatsapp; farmer discussions, Q&A

REVENUE MODEL

Freemium subscription service

Donor funding

207 CGIAR and CIAT (2016–2019). Informing sub-national climate smart agriculture investments in Kenya: county climate risk profiles.

Upon registration, farmers are asked to provide their location, crops/livestock produced and other agronomic practices. Location is captured as a combination of the sub-ward and closest landmarks, which allows localisation to several kilometres. Using this information, tailored messages are sent to farmers. The findings from the CRPs have been developed into a searchable database that call centre staff, themselves qualified agricultural experts, use to provide advice to farmers who call the iShamba hotline.

Currently, the service has scaled to more than 500,000 subscribers across Kenya through its links to Shamba Shape Up and the DigiFarm platform. A recent independent impact study conducted by 60db has shown that 90 per cent of farmers have reported improvements in their farming practices, farm production and revenue and overall quality of life due to the information services provided by iShamba.[208] For 83 per cent of the farmers, iShamba is the only information service of its kind available to them. Almost all farmers reported increased income from farming activities due to iShamba and 50 per cent reported a positive impact on recovery from a climate shock. In terms of users, iShamba was found to have a relatively high user base among more affluent farmers in Kenya and could do more to reach poorer farmers.

208 Mercy Corps AgriFin. (2021). 60 decibels Impact Series: iShamba.

CASE STUDY

IFFCO Kisan, India

In 2007, the Indian Farmers Fertiliser Cooperative Limited (IFFCO) and Bharti Airtel, the largest MNO in the country, joined forces to establish IFFCO Kisan Sanchar Limited (IKSL) and provide Green SIM, a packaged service providing voice-based agricultural information to farmers. The GSMA provided seed funding and technical assistance during the early stages of service development. In the years that followed, Green SIM scaled to provide a mix of content through a variety of channels to more than four million users in 2021, pioneering the provision of commercially sustainable digital advisory services to rural populations. The organisation has also been managing the Government of India's Kisan Call Centre (KCC) since 2015.

Driven by the limitations of call centres to meet fluctuating demand, the limited bandwidth of voice messages and increasing adoption of smartphones among farmers, IFFCO Kisan continues to innovate in the provision of digital agricultural services. It has most recently pioneered dynamic and localised advisory services through their mobile app and Krishi Dev Gyan (KDG) platform, which use a combination of remote-sensing, IoT and ground-level data sources analysed through artificial intelligence (AI) and crop models.

At its core, the service uses remote-sensing data to collect information about plant health, soil moisture and nitrogen requirements. Weather data and forecasts are sourced from the India Meteorological department and private weather forecasters. Crop modelling tools, such as Aquacrop, are used to assess ideal times for irrigation and harvest activities. Working with content from local agricultural research institutes and agencies, and agricultural universities for content development, an in-house team of agricultural experts tailors advisory messages based on the collected data. Using this approach, IFFCO Kisan provides localised advisory services to more than 100,000 farmers.

PARTNERS

IFFCO Kisan (service owner, agritech)

Indian Farmers Fertiliser Cooperative Limited (IFFCO)

Bharti Airtel (MNO)

Star Global Resources Ltd. (business services)

Krishitantra (soil testing)

DATA SOURCES FOR CONTENT DEVELOPMENT

Weather data (India Meteorological Department, private weather agencies)

Soil data (Krishitantra)

Crop models (Aquacrop, APSIM)

In situ observations (field scouts/digi-walkers)

DATA TYPES USED FOR LOCALISATION

Crops/livestock

Location

Farm boundary mapping (digi-walkers)

DISSEMINATION CHANNELS

Call centre

IVR and SMS

Mobile app

Field agents

REVENUE MODEL

GreenSIM sales

Input sales, produce aggregation

IFFCO Kisan has also started working closely with agricultural stakeholders to enable the collection of PA data for more accurate and reliable advisory. Focusing on a specific region, they work with local farmer producer organisations (FPOs), agribusinesses and research institutes to understand key crops grown, requirements of agri buyers and agricultural and climate challenges. They provide weather stations to FPOs, typically financed by NABARD,[209] which feed data into their models. Soil information was identified as a key data input and is collected by partner organisation Krishitantra,[210] which builds the capacity of an FPO member to conduct soil testing using a portable kit. This service is subsequently run as a sustainable independent business and enables further localisation of advice. In addition to self-registration through the mobile app, field agents employed by IFFCO Kisan collect farmer data to register them to the service, including know-your-customer (KYC) data, geofencing, crop variety, sowing date and inputs used. This model currently covers more than 20,000 farms.

Advice on climate-smart agriculture is provided periodically to farmers as a complement to other agronomic practices. This advice focuses on the application of specific CSA practices and recommendations of climate-smart crops and varieties suited to the farmers' area. IFFCO's main challenge in the provision of CSA advice is a lack of content. IFFCO Kisan requires a consistent flow of crop-specific information to tailor advisory content to CSA, which is not yet available from their content partners.

6
Precision agriculture

Precision agriculture (PA) services bring intelligence and advisory services to the farm level by using farm-specific agronomic data, such as on-farm sensors, soil analysis and high-resolution remote-sensing data from unmanned aerial vehicles (UAVs) or private satellite providers. This shift from general to more specific data enables more tailored recommendations on crop choices, input use and good agricultural practices, which ultimately help to maximise agricultural productivity.

This approach results in services that are very distinct from digital climate advisory services (DCAS) as they provide advice on a limited number of agricultural decisions, although with much greater specificity across an area that extends to several thousand square metres. They also rely almost solely on automated data analysis using artificial intelligence (AI) or other software rather than the expert assessment required to interpret the many data sources used in DCAS. Finally, their reliance on in situ hardware limits their scalability compared to the basic phone and field agent modes of delivery of DCAS.

Photo: Georgina Smith (CIAT)/flickr

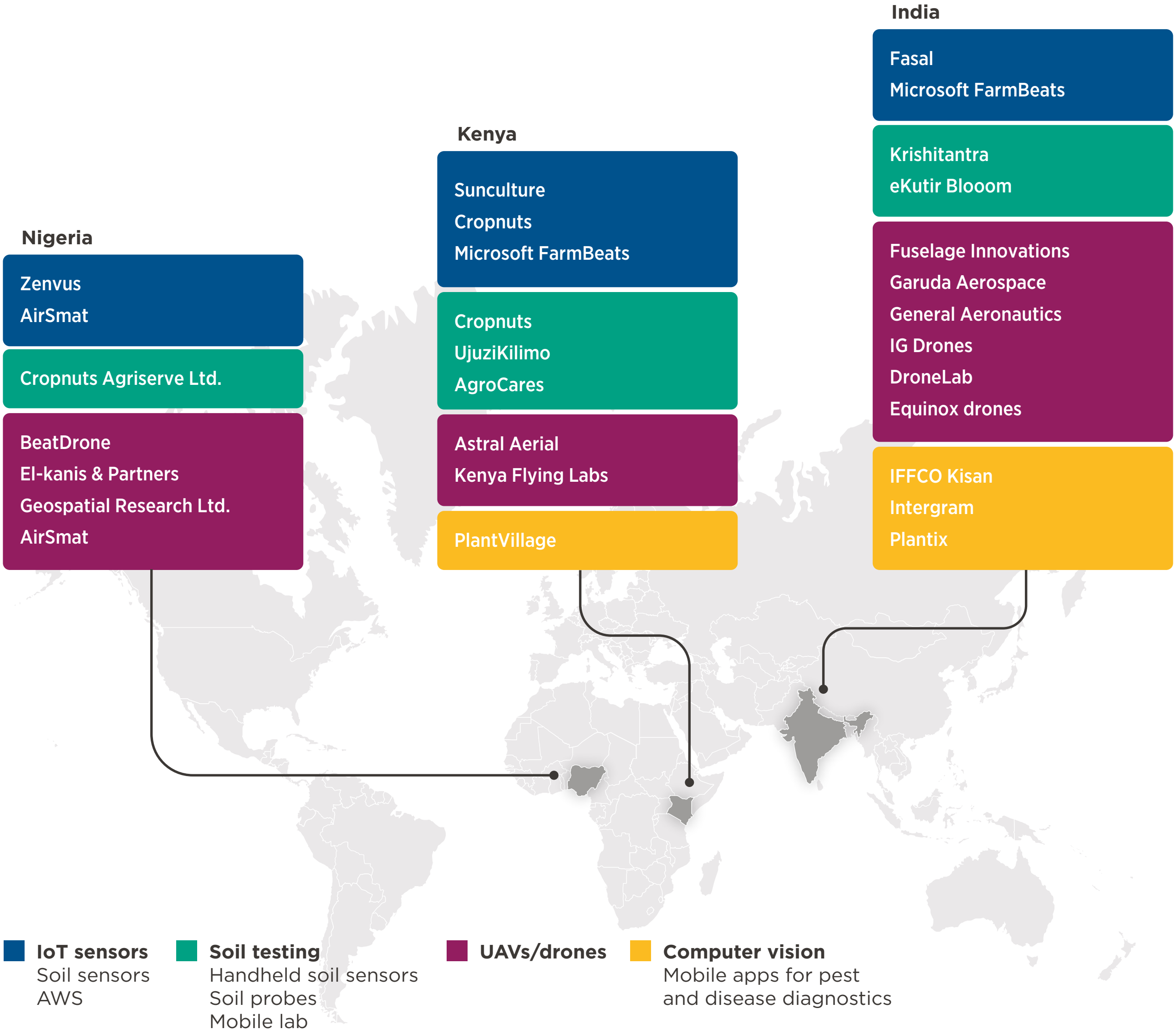
6.1 Landscaping services in India, Nigeria and Kenya

The PA space is currently comprised of organisations that create services based on a technology platform in which they have the required expertise.

These technology platforms are Internet of Things (IoT) sensors such as soil sensors and AWS that monitor on-farm conditions, mobile soil testing services that measure soil composition, UAVs or drones that monitor fields and provide spraying services and computer vision analysis delivered through mobile apps that use smartphone cameras to diagnose crop pests and disease. The characteristics of these technologies strongly influence the types of services that can be created, as well as the business models required to commercialise them.

Figure 16

Landscaping of PA providers operating in the target markets



Source: GSMA AgriTech

6.2 Business models

In contrast to DCAS, where business models are characterised by service ownership and partnerships for service creation, in PA, the technology providers are the service owners and partnerships do not play a significant role.

Key challenges to service provision in PA are related to establishing scalable methods to distribute hardware, as well as identifying sustainable revenue models to cover the costs of hardware, software and ongoing maintenance. An exception to these challenges is the provision of computer vision services through mobile apps. Due to the digital-only nature of this type of service, which uses smartphone cameras, there are a different distribution and revenue generation challenges.

Table 4

PA approaches to distribution and revenue generation

	IoT sensors	Soil testing	UAVs/ drones	Computer vision
Hardware distribution model	Sale of hardware to commercial farmers, governments and cooperatives Representatives are trained to operate and maintain the device, and to deliver localised advisory to beneficiaries	Sale of hardware to farmer organisations and fertiliser companies Representatives are trained to conduct soil tests and, in some cases, to provide services as a micro-business	Provision of services through UAV operators to commercial farmers and farmer cooperatives	Mobile app
Revenue model	Payment for device + subscription	Payment for device + subscription/licence fee	Payment for services	Donor-funded Subscription Data monetisation Cross-subsidisation

Source: GSMA AgriTech

Technology solutions provided by IoT sensor providers consist of one or more hardware devices, and a software platform for analysis and visualisation of the data collected to provide advice. Devices for soil monitoring start at $200 to $300 and data connectivity is usually achieved through mobile data networks. Low-power wide-area[211] IoT networks can enable the use of low-power, long-range and low-cost devices, and could greatly increase the scalability of IoT approaches. Currently, hardware devices are sold to business customers and access to software is provided on a subscription basis. This model presents several challenges to smallholder farmers, including high upfront acquisition costs and the technical knowledge required to operate the device.

To overcome these challenges, Zenvus in Nigeria sells their hardware to government agencies and farmer cooperatives that make them available to farmers. To enable this approach, GPS sensors are included in the device to detect movement to new locations as the device is shared by members of the farmer cooperative. Purchase of the device includes training of one cooperative member to operate and maintain the device and provide advisory to other cooperative members. Cooperatives can access loans from the Bank of Agriculture to purchase the devices. In India, Fasal focuses on the commercial horticulture sector in which farmers can afford to purchase the devices, and the productivity improvements related to lower input costs and higher yields justify the upfront purchase costs.

211 Low-power wide-area network (LPWAN) is a wireless network technology that interconnects low-bandwidth, battery-powered devices with low bit rates over long ranges. Created for IoT networks, LPWANs operate at a lower cost with greater power efficiency than traditional mobile networks. They can also support more connected devices over a larger area.

Soil testing providers face very similar challenges to those described above, but whereas IoT sensors are typically used to monitor conditions in a specific location, soil testing devices can service many locations. This makes them more suited to delivery through an agent network, with community members becoming microentrepreneurs delivering soil testing services. Krishitantra in India, Cropnuts in Kenya and Cropnuts AgriServe Ltd. in Nigeria all sell mobile soil testing laboratories to agribusinesses, input providers and farmer organisations and provide training to designated members to deliver services. Cropnuts and Cropnuts AgriServe Ltd. specifically target agribusinesses working with outgrowers to provide affordable soil testing services. Licensing fees are paid to provide soil testing services to their communities and cover access to the software, providing analysis results and advisory.

The combination of high hardware costs, demand for significant expertise and licences required to operate UAVs means that drone services are offered to farmers and farmer organisations as paid services. Due to the cost of moving drone operators on site and the capacity of drones to cover large areas of land in a single visit, services are typically acquired by farmer organisations or large commercial farmers. Operational scalability of UAV providers is limited by their network of licensed UAV operators. As this is a highly specialised task, companies such as BeatDrone in Nigeria have developed their own training centres to train and license operators. Regulatory restrictions in this emerging space also pose challenges to operators that may need to get approvals and licences from several government agencies before being able to operate their services.

Computer vision software providers have a very different profile than hardware-based providers since their services are distributed through mobile apps running on user-owned hardware – smartphones. Leading providers of these services use different business models. Plantix, which has focused on the Indian market, provides their services through a free app and has an annual user base of more than 10 million. While computer vision to diagnose crop disease is at the core of their services, Plantix has partnered with agricultural research institutes to provide comprehensive advisory content. They are investigating several revenue streams, including monetising usage data through sales to input providers and selling inputs to users through their app. PlantVillage, part of Penn State University, operates with donor funding to deliver a range of data-driven advisory services (DDAS) services to smallholder farmers across Africa. IFFCO Kisan in India has integrated computer vision capabilities in their mobile app, which also provides revenue-generating services such as input markets.

6.3 Service creation

The service creation steps in PA rely less on partnerships and more on analysis of collected data to provide very specific agricultural advice. As such, these services do not have to rely on expert assessment to provide advisory, but they are also significantly limited in the range of agricultural decisions they can support.

As the enablers and challenges vary depending on the technology used, this section provides an overview of the service creation steps for each PA-enabling technology. This section uses the framework of service creation steps presented in section 3.1 (see Figure 5) to evaluate PA service creation and delivery.

IoT sensor services provide the hardware to collect data on several indicators, as well as services that analyse this data and provide advisory through mobile apps. The most commonly used soil sensors collect data through optical or electrochemical sensors and use dedicated software to convert the raw data into measurements of soil moisture, soil temperature, pH and nutrients. These observations are then compared to ideal values based on crop requirements to make recommendations on irrigation, fertiliser application and pest and disease risk. In India, Fasal builds on this approach by also providing AWS to capture basic meteorological data, enabling early warnings for pest and disease, and microclimate forecasting, using local observations to train AI that localise publicly available forecasts. Advice is typically provided through smartphones to device owners. In cases where devices are sold to farmer cooperatives, an individual is trained to manage the device and access the advice. This person is responsible for moving the sensor between fields and providing advice to farmer members.

Soil testing services use mobile labs or handheld sensors to provide soil nutrient measurements to smallholder farmers. A key enabling technology for soil testing services is the use of portable soil scanners using spectroscopy, which has significantly reduced the cost of soil analysis. To analyse the raw data, machine learning algorithms are trained on large datasets of laboratory-tested soil samples. Such datasets are relatively uncommon in low- and middle-income countries (LMICs) and limit the application of this technology. Cropnuts, which has been lab-testing soil in Kenya, and across East Africa, for more than 20 years, has built such a dataset and use it to develop their mobile FarmLab solution. This solution is available in Kenya and Nigeria and is delivered through Cropnuts' own services or through licensed providers. Advice is provided in the form of reports that identify nutrient deficiencies and make locally available fertiliser recommendations based on crop nutrient requirements. AgroCares provides a similar solution, albeit in a more portable format, that enables microentrepreneurs to provide soil testing due to the smaller size and lower cost of the testing device. Analysis is conducted in the cloud, with results and recommendations delivered to the smartphone of the operator within 10 minutes.

UAV services use drone-mounted sensors to observe a range of agricultural phenomena at high resolution. Collecting data requires licensed UAV operators to conduct data-gathering flights over fields of interest in a predetermined flight path and consistent altitude. The collected imagery is processed through dedicated software that overlays it on Geographic information system (GIS) maps and processes it to provide agronomic indicators such as plant health, soil moisture and nutrient content, as well as identify weeds and predict yields. Due to the complexity of processing raw UAV imagery into agronomic indicators, few UAV service providers do it in-house, relying instead on specialist software such as DroneDeploy or Sentera, which provide reports that can be shared with end users.

Organisations using **computer vision** to provide pest and disease diagnostics rely on users to collect the relevant data using their smartphone. This can be done in the field where the user takes an image of the affected plant. In the PlantVillage app, this image is analysed using machine learning algorithms that run locally on the smartphone, which means data connectivity is not required. Algorithms to detect plant disease are typically developed in-house by the service provider, as in the case of Plantix, which has developed tools that can identify more than 500 pests, diseases and nutrient deficiencies in more than 50 crops with more than 85 per cent accuracy. Once the issue has been identified, the app provides relevant content to the user on management options. In the case of Plantix, this content is developed in cooperation with national and international agricultural research institutes and extends beyond pest and disease management to cover good agricultural practices throughout the crop cycle. PlantVillage provides access to their own library of good agricultural practices through their app. While the apps are typically offered for free, the cost to purchase and use smartphones remains a limiting factor to adoption, especially among subsistence farmers and marginalised groups. The availability of low-cost handsets and data in India were what prompted Plantix to start operations there, resulting in a boom of adoption in rural communities. PlantVillage, on the other hand, provides smartphones to targeted farmers as part of their donor-funded projects.

CASE STUDY

Cropnuts, Kenya and Nigeria

Cropnuts is an independent agricultural and environmental testing laboratory based in Kenya with offices in Nigeria and Zambia. Amongst other services, it provides testing of soil, water, crops, animal feed and fertilisers. Having provided services to commercial and smallholder farmers, and conducting field trials since 1998, Cropnuts has built an extensive repository of agricultural data and knowledge. While traditional lab-based testing is largely out of reach for smallholder farmers, Cropnuts has recently launched AgViza Clinic, an AI-based soil testing and digital crop advisory service.

According to Cropnuts, AgViza reduces the cost of soil testing by 75 per cent and eliminates the need for wet chemistry lab work through a combination of portable spectral soil analysis calibrated using Cropnuts' extensive soil sample database. Business partners, including fertiliser companies, produce aggregators, public sector extension and development organisations, purchase the equipment and pay an annual licence fee to provide soil testing services. Farmers pay for the test and register for Cropnuts' AgViza Client app, or receive results through email, text or SMS which includes specific locally available fertiliser recommendations. This approach is enabling soil testing to be scaled up among smallholder farmers who have previously been excluded from such services. However, considerable barriers remain due to the cost of service delivery to farmers, driven by the need for a trained and equipped agent network.

PARTNERS

Licensees:
- Input providers
- Agribusinesses
- Extension services

DATA SOURCES FOR CONTENT DEVELOPMENT

AI-enabled soil testing (AgViza)

In-house agricultural data repository

DATA TYPES USED FOR LOCALISATION

N/A

DISSEMINATION CHANNELS

Mobile app

REVENUE MODEL

Licensing of AgViza technology

CASE STUDY

Plantix, India

Berlin-based PEAT Technology has a mobile app that uses image recognition to diagnose crop diseases and recommend the appropriate course of treatment. Their automated image recognition health check can identify more than 500 pests, diseases and nutrient deficiencies for 50 crops with more than 85 per cent accuracy. Plantix continuously improves the algorithms through validation trials in farmers' fields.

Recognising the rapid increase in smartphone adoption in India, including in rural areas, PEAT decided to target their service offering to that market. Working with ICRISAT, CABI, the Government of Andhra Pradesh and state agricultural universities, PEAT first tailored their offering for the southern states before adapting them to the rest of the country. Launching in Andhra Pradesh with support from the local government, they leveraged interest from local TV stations and social media to disseminate Plantix throughout the state. The app is currently available in 18 different languages and 150 countries and has more than 70,000 daily active users.

From an early stage, PEAT has been successful in raising investment for the development of their services after participating in the Merck Accelerator. Using the app is free and revenue comes from the sale of usage data to input providers and chemical companies. The company has expanded the app by bundling an agricultural inputs marketplace, which has been strengthened through the purchase of the Indian e-commerce platform Salesbee, and integrating functionality and registered input providers from Salesbee in their own app.

PARTNERS

International Crop Research Institute for the Semi-Arid Tropics (ICRISAT)

Centre for Agriculture and Bioscience International (CABI)

Indian Agricultural Universities

Government of Andhra Pradesh

DATA SOURCES FOR CONTENT DEVELOPMENT

Computer vision using smartphone camera

DATA TYPES USED FOR LOCALISATION

GPS

DISSEMINATION CHANNELS

Mobile app

REVENUE MODEL

Data monetisation

Input sales

CASE STUDY

Beat Drone, Nigeria

Nigerian start-up BeatDrone offers UAV services for agriculture, infrastructure businesses and the oil and gas industry. It provides monitoring and spraying services to a range of agricultural stakeholders including aggregators, farmers associations and cooperatives, governments and financial institutions. Services include mapping, monitoring and spraying of agricultural fields, as well as planting of trees and crops. Monitoring includes pre-planting assessment of soils to make fertiliser recommendations, as well as in-season monitoring to troubleshoot crop health issues and predict yields. Data is analysed using the proprietary Drone Deploy software, which converts images into Geographic information system (GIS) maps and provides visualisations of problem areas, yield estimates and soil nutrient content estimates. Their fertiliser advisory and spraying services typically result in a 40 per cent reduction in the amount of chemicals used and a 60 to 80 per cent increase in yields.

To make services accessible to smallholder farmers, BeatDrone works with farmer cooperatives that pool demand from members to share the cost of a service, which can cover several farms during a single visit. Scaling up operations for BeatDrone relies on increasing the number of drones and drone operators to provide services. To achieve this, BeatDrone has set up BeatDrone Academy, which provides training to aspiring drone operators to build, maintain and operate drones, and serves as preparation for obtaining a drone operator's licence from the Nigerian Civil Aviation Authority.

PARTNERS
AgroXchange

DATA SOURCES FOR CONTENT DEVELOPMENT
UAVs

DATA TYPES USED FOR LOCALISATION
GPS

DISSEMINATION CHANNELS
Mobile app
Reports

REVENUE MODEL
Payment for services

7

Key messages

The contribution of data-driven advisory to climate-smart agriculture

Drawing on the frameworks and landscaping of data-driven advisory services (DDAS) providers in the preceding chapters, this chapter will provide conclusions on the extent to which the different approaches to DDAS are supporting climate-smart agriculture (CSA) adoption by smallholder farmers, which CSA practices are benefiting most and how successful service creation and business models provide opportunities to strengthen the impact of DDAS on CSA adoption.

While many of the services reviewed in the research did not explicitly address CSA, they provide advice that enables the implementation and optimisation of several practices that contribute to the three CSA pillars of increased productivity, enhanced resilience and reduced emissions.

DDAS are naturally suited to optimising farming systems to meet CSA goals.

From the initial assessment of impact of DDAS on CSA (Table 5), CSA practices are further distinguished between those that optimise current agricultural systems and those that support the transition to a new agriculture system. The optimisation of farming systems involves choosing appropriate seed, managing fertiliser application and timing agricultural practices based on weather conditions to maximise their impact. In these examples, a farmer would typically be able to adopt one or more CSA practices throughout the cropping season and realise the benefits of implementation. With practices that require a transition to a new agricultural system, including conservation agriculture (CA) and IPM, choices are made at the start of the season that have implications for management practices throughout the season or year, and therefore require a much higher level of commitment and expertise by farmers to implement.

Table 5

Expected impact of DDAS advisory on CSA adoption

	DIGITAL CLIMATE ADVISORY SERVICES		PRECISION AGRICULTURE			
Optimise farming systems	Advisory only	Bundled services	IoT sensors	Soil testing	UAV services	Computer vision
Crop tolerance to stress	Low	Medium	Low	Medium	Low	Low/Medium
Fertiliser management	Medium	High	Medium	High	Medium	Low/Medium
Pest and disease management	Medium	High	Medium	Low	Medium	High
Climate services	Medium	High	Medium	Low	Low	Medium
Water management (optimisation)	Low	Medium	High	Low	Medium	Low/Medium
Transform farming systems						
Water management	Low/Medium	Low	Low	Low	Low	Low
Intercropping	Low/Medium	Low	Low	Low	Low	Low
Crop rotation	Low/Medium	Low	Low	Low	Low	Low
Organic inputs	Low/Medium	Low/Medium	Low	Low/Medium	Low	Low
Conservation agriculture (CA)	Low/Medium	Low	Low	Low	Low	Low
Integrated pest management (IPM)	Low/Medium	Low	Low	Low	Low	Low/Medium

Low   Medium   High

Source: GSMA AgriTech

Table 8 identifies the contribution of various types of DDAS to enabling CSA approaches in the field. This analysis is based on the assessment of the author, as there is little impact data available linking advice provided by DDAS solutions to the contribution of this advice to the three CSA pillars.

Due to the nature of their services, data-driven agricultural advisory is best suited to practices that enable the optimisation of farming systems. DDAS typically provide short pieces of advice, limited by the bandwidth of digital delivery channels, that are customised to current weather conditions and the local farming context. Such short dynamic advisory services are well suited to guiding day-to-day agricultural decisions, but less so to decisions about what to grow and how to grow it as required by transformative practices. Even in cases where DDAS provide decision-making support at the start of the season, based on seasonal forecasting, these decisions typically relate to decisions about crop varieties and planting dates that will maximise the predicted seasonal conditions. Approaches to introducing more fundamental changes in farming practices, such as intercropping, CA and IPM, typically use face-to-face and participatory approaches to sensitise farmers to the approaches and build their skills.[212] Relying on digital services alone is not likely to build the trust and ability of farmers to implement these complex practices.

Digital climate advisory services (DCAS) have the greatest CSA impact due to their comprehensive advisory and greater potential to scale. Precision agriculture (PA) provides highly localised advice for a limited number of agricultural practices.

Most of the impact on CSA is expected to be achieved by DCAS due to the range of agricultural practices covered by the advice, and the scalability of the approach. DCAS draw extensively on good agricultural practices throughout the cropping cycle, filtering and tailoring them to local contexts using a range of data sources. They also provide the most accessible services, often requiring only a basic phone to access content. PA services, on the other hand, provide advice on a limited number of decisions and require the purchase of hardware, farm visits or smartphone ownership, which pose challenges to scale, at least in the short term. Unmanned aerial vehicle (UAV) and computer vision approaches provide relatively higher impact with PA services due to the wide applicability of data collected, and through in-app bundling of advisory content, respectively.

Bundled DCAS are highly scalable in commercial value chains while subsidised advisory-only DCAS can champion CSA and serve marginalised groups.

Within DCAS, bundled services are more likely to have an impact on optimisation practices due to higher resolution data from agent networks and PA partners, as well as transaction data from bundled services. These additional services also provide access to the inputs, services and/or markets that enable farmers to put advice into practice. In markets that reward sustainable practices, bundled DCAS providers are effective catalysts for transformation due to their comprehensive service provision and ability to provide traceability through field-level data collection.

Subsidised advisory-only services have an important role to play in serving subsistence farmers and groups excluded from the value chains served by commercial bundled services, as well as in championing transformational CSA practices. Ownership or close collaboration with public extension services and donors mean they can support on-the-ground capacity building programmes for transformational CSA practices, such as CA or IPM. In these contexts, DCAS can be used as a complementary tool that provides prompts and reminders of practices to implement.

212 Bourne, M. et al. (2020). Participatory versus traditional agricultural advisory models for training farmers in conservation agriculture: a comparative analysis from Kenya.

Advisory content on CSA practices from agricultural research institutes is a cornerstone of effective DDAS.

In the provision of DDAS in the three key markets, agricultural research institutes played a key role in data collection and content development activities. Landscaping of services across the key markets revealed that most approaches to DDAS provision, whether bundled or advisory-only, rely on content from national or international agricultural institutes. Yet while research institutes enable DDAS through the provision of advisory content, many have not yet developed CSA-specific content for the major crops that can be provided on an ongoing basis.

More research is needed to develop CSA-specific content DDAS providers need to develop their services, including:

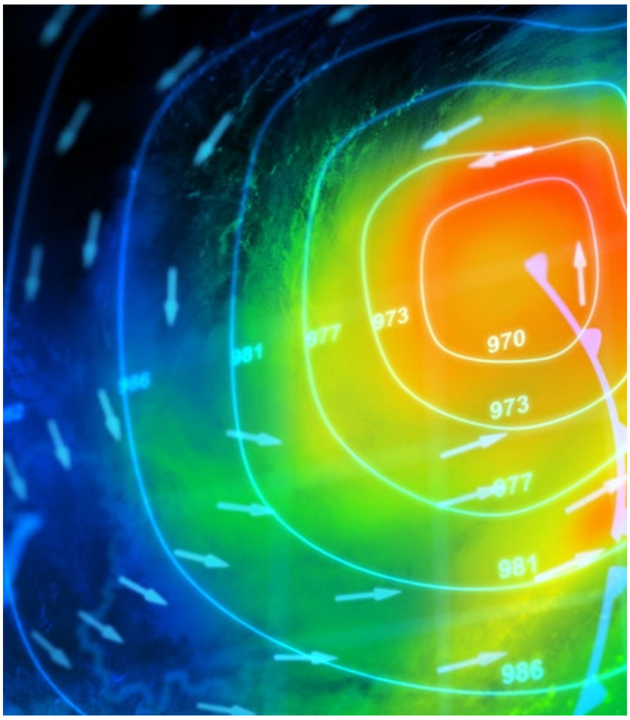
- The identification of practices that address the CSA pillars in local contexts and provide advice on the implementation of these practices. This will provide localised content on climate-smart agricultural practices and their application. To maximise the impact of this data, it is important that it is openly available in a searchable digital database, allowing selection based on relevant localisation parameters.
- The development of crop models that (further) integrate the impact of climate factors and extreme climate events on different crop stages and overall crop yields. This will enhance sensitivity to actions that can improve productivity and adaptation in the face of climate change.

Accurate and localised weather and climate services are crucial to effective DDAS service creation.

Weather observations, forecasts and climate predictions can support decision-making throughout the cropping cycle. Despite this wide applicability and high-potential impact, relatively few initiatives were found to use weather data, and those that did often cited a lack of localisation and reliability. To address this, some bundled DCAS providers deploy AWS with farmer groups to enable local observations and downscale weather forecasts. However, due to the cost and expertise required this approach is not feasible for most DDAS providers. Other opportunities are available for DDAS providers to source weather data in the absence of reliable public services.

Access to improved weather services can be enabled by collaborations with:

- Organisations that can extend in-country weather observation infrastructure, including non-governmental organisations (NGOs) (e.g. TAHMO,[213] which is developing a network of weather stations in Africa) and MNOs (which can co-locate AWS with mobile base stations or observe rainfall through CML data).[214]
- Private weather forecasters that use innovative weather modelling (e.g. Ignitia,[215] Weather Impact[216]) or data acquisition from alternative sources, such as cube satellites (e.g. TomorrowNow.org[217]) or lightning sensors (e.g. Earth Networks[218]) to localise their forecasts.



213 https://tahmo.org/
214 GSMA. (2021). Digital Innovation for Climate-Resilient Agriculture.
215 www.ignitia.se
216 www.weatherimpact.com
217 www.tomorrownow.org
218 www.earthnetworks.com

Partnerships between agricultural research institutes and DDAS providers can enable the production and scalable distribution of effective CSA content.

Most DDAS providers profiled in this research collaborate with agricultural research institutes to interpret collected data to formulate advisory messages, or to assure the quality of advisory content prior to publication. In return, agricultural research institutes benefit the dissemination of their advisory content through additional digital channels, deepening their impact. These mutually beneficial relationships can be deepened to unlock further synergies.

Opportunities to deepen these collaborations to develop and scale up CSA practices include:

- Bundled DCAS providers present an unprecedented opportunity to collect data on agroclimatic conditions (from sensors, remote sensing), agricultural practices (through field agent monitoring), input use (from transaction data) and yields (from transaction data) at scale. This data can be used internally or shared with agricultural research institutes to identify context-specific CSA and develop associated advisory content.
- Agricultural research institutes and DDAS providers can co-create CSA practices that lower thresholds to adoption and maximise impact. Agricultural research institutes can simplify transformative CSA practices to reduce the knowledge required for implementation and make them more amenable to dissemination through DCAS. HCD approaches to developing and monitoring adoption of these practices by DCAS providers will optimise the recommended practices and advisory services.

Partnerships for ground-level data collection and service delivery will increase the impact of public DCAS.

Ground-level data collection through field agents and PA providers by bundled DCAS providers has been shown to create an unprecedented amount of data for customising advisory and targeting services. Public- and donor-funded advisory-only services face significant challenges in collecting the same level of data since they lack the economies of scale to fund field extension services and PA data collection. This has an impact on the provision of DCAS to marginalised groups and the provision of CSA to commercial value chains, as neither are prioritised by bundled DCAS providers.

Opportunities to improve ground-level data collection and service customisation by advisory-only DCAS include:

- Partnering with bundled DCAS providers where available, to share on-the-ground infrastructure to provide CSA advisory to commercial value chains. This approach is taken by Farms and Farmers and the Environmental Defense Fund, which are partnering with DeHaat to use their app and network of DeHaat centres to access inputs, advice and markets that will enable adoption of rice intensification practices.[219]
- Building a shared digital agent network for the execution of field-level tasks by organisations serving rural populations. This would require partnering with and investing in existing extension networks, farmer groups, agribusiness, PA and/or input providers. Central, farmer-owned data repositories such as FarmStack[220] can enable such collaborations through enabling data sharing across organisations, with mobile money-enabled payments for services facilitating agent remuneration.

219 Environmental Defense Fund. (2016). Farm and Farmers (FnF) in collaboration with Environmental Defense Fund (EDF) launch the DeHaat App at the event 'Pratibimb-Prakrishi Samyukt, DeHaat Ekjut'.
220 Digital Green. Catalyzing the Data Sharing Ecosystem – Introducing FarmStack.

Bundled DCAS providers are well placed to provide incentives to drive farmer adoption of transformative CSA practices.

A perceived mismatch between the risks and benefits of transformative CSA practices are a key barrier to the adoption of transformative CSA practices. Often, the long-term benefits of improved productivity and lower input requirements associated with practices such as CA, for example, do not outweigh the short-term risks of reduced income. In other cases, value chains are not able to reward sustainable practices due to a lack of traceability and/or markets for sustainable produce. Additional, immediate incentives are likely to stimulate adoption of transformative practices.

Bundled DCAS providers have several opportunities to address these issues:

- Where markets for sustainable produce exist, bundled service providers can provide the digital and physical infrastructure required to provide access to producers. Due to their close relationship with farmers, and the data collected throughout the cropping cycle, they are well placed to enable the traceability required to secure premiums for sustainable produce. When passed on to farmers, these premiums provide strong incentives to adopt CSA practices.
- A more nascent opportunity involves the creation and sale of carbon credits from the mitigation impacts of CSA practices, which can provide an additional monetary incentive for CSA adoption. Current approaches include the use of satellite remote sensing to quantify changes in soil carbon content[221] or rice methane emissions,[222] or the collection of farm-level data to enable credible claims on emissions reductions.[223] As organisations with remote-sensing expertise, and farm-level data collection already in place, bundled DCAS providers are well placed to explore the implementation of these approaches to encourage CSA adoption

Impact measurement frameworks developed and implemented by agricultural research institutes and DDAS providers can drive future research in CSA.

Measurement of the impact of providing DDAS to smallholder farmers on CSA pillars is scarce and frequently limited to impact on the first pillar – the productivity and profitability of farmers. For commercial DDAS providers, this provides an indication of the value they are providing to their customers and is therefore a key business metric. Measuring impact on adaptation and mitigation of climate change is less directly relevant, and more challenging to quantify. While some subsidised DDAS measure impact on smallholder resilience and reduced emissions, they use a variety of approaches, often qualitative, which limits the lessons that can be shared across approaches.

Opportunities to improve CSA impact measurement of DDAS provision include:

- The development of clear and standardised impact measurement frameworks to assess adaptation and mitigation impacts. International research institutes and CSA implementers are best placed to lead framework development and should specify which data will facilitate impact assessment, taking into account the digital data collection and analysis approaches used by DDAS, such as satellite remote sensing and crop modelling.
- Additional incentives for impact monitoring by DCAS providers to drive widespread adoption. Such incentives are most effective where impact assessment aligns with commercial goals, such as requirements for the traceability of sustainable produce by agribusinesses or markets, or for monitoring, reporting and verifying data that can enable the monetisation of greenhouse gas (GHG) emissions through carbon credits. Demonstration of impact to funders will be strong drivers of impact assessment by subsidised DCAS providers.

221 Boomitra.
222 GeoTree.
223 Digital Green. (2021.) Seminar on the Role of Technology & Data Science in Accelerating Climate Smart Agriculture Outcomes: Outcome Report.

Glossary

A/B testing is an experiment in which two or more variants of a service are shown to users at random, and statistical analysis is used to determine which variation performs better for a given conversion goal.

Agroforestry is an integrated land use management practice that involves growing trees, shrubs and hedges on the same land unit as agricultural crops and/or animals to increase agricultural yields, improve soil conditions and enhance the sustainability and functionality of the farming system.

Artificial intelligence (AI) is a constellation of many different technologies working together to enable machines to sense, comprehend, act and learn with human-like levels of intelligence.

Biotic stress is the damage caused to plants by other living organisms, such as parasites and pathogens (virus, bacteria, fungi, nematodes or insects).

Business to business to consumer (B2B2C) services enable businesses to provide consumer-facing services.

Carbon sequestration is the process of capturing and storing carbon in plants, soils, geologic formations and the ocean. It is one method of reducing the amount of carbon dioxide in the atmosphere to slow global warming and mitigate climate change.

Chatbots are software that use artificial intelligence (AI) and natural language processing (NLP) to simulate human-like conversations with customers through multiple channels, such as messaging apps, website chats, voice assistants and customer contact centres.

Climate change adaptation refers to adjustments in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change.

Climate change mitigation describes efforts to limit the magnitude and/or rate of long-term climate change. It involves taking action to reduce or stabilise emissions and remove heat-trapping greenhouse gases (GHGs) such as carbon dioxide (CO2) and methane (CH4) from the atmosphere.

Climate resilience is the ability to mitigate and adapt to the impacts of climate change. It involves having the capacity to anticipate climate risks and hazards, absorb shocks and stresses and reshape and transform development pathways in the longer term.

Climate-smart agriculture (CSA) was developed as a framework to guide the transition of agricultural systems to achieve sustainable development in the face of intensifying impacts of climate change. CSA charts development pathways that can be used to achieve three interlinked goals: Increased productivity and profitability, adaptation to climate change and mitigation of climate change. CSA is not a set of practices, but provides the means to identify, develop and measure practices that enable the transition to sustainable agricultural systems. As an approach defined by outcomes, CSA does not refer to specific agricultural practices, as these may be climate smart in one context, but not in another. Context-specific impact is key.

Conservation agriculture (CA) is a farming system that can prevent losses of arable land while regenerating degraded lands. CA improves soil quality through minimum soil disturbance, maintaining soil cover and crop rotations with a diversity of crop species.

Crop modelling involves the use of mathematical algorithms to capture the quantitative information of agronomy and physiology experiments in a way that can explain and predict crop growth and development.

Data-driven advisory services (DDAS) enable evidence-based decision-making through the integration of a variety of data sources, including satellite imagery, weather data and farm profiles. DDAS use a variety of data sources, including satellite imagery, sensor data, weather data and farm profiles, as well as artificial intelligence (AI) and other analysis methods to support the decision-making of smallholder farmers and other value chain actors, such as agribusinesses and input providers. DDAS encompass both macro agri-intelligence services that analyse agricultural activity at a country or regional level for large organisations or public institutions (B2B/B2G), as well as farmer-facing (B2C/B2B2C) services such as digital climate advisory services or precision agriculture (PA) services that use time- and farm-specific data on weather, climate and agronomic variables to provide tailored advice on agricultural practices.

Digital climate advisory services (DCAS), tailor advisory content based on dynamic agroclimatic conditions at the farm location, for example, information on soil type, crops cultivated, length of cropping cycle and weather forecasts, enables relevant advice at the right time on planting, input application, crop management and harvesting.

Ecosystem services are the benefits people derive from ecosystems, including the provision of food, wood and other raw materials, as well as essential regulating services, such as pollination of crops, prevention of soil erosion, water purification and cultural services such as recreation and spiritual fulfilment.

Eutrophication occurs when an aquatic ecosystem such as a lake receives an excessive nutrient load of phosphorus, nitrogen and other plant nutrients. This often results in an overgrowth of algae. As the algae die and decompose, oxygen is depleted from the water, and this lack of oxygen causes the death of aquatic animals, like fish.

Fertiliser microdosing is a strategic fertiliser placement technique to increase the efficiency of fertiliser use, reduce investment costs for resource-poor small-scale farmers and increase crop growth and productivity.

Integrated pest management (IPM) promotes biological control of pests and diseases, good agronomic practices and the use of other means to control pests besides chemical residues. It is based on four practical principles: Grow a healthy crop, conserve natural enemies, observe fields regularly and farmers become experts.

Intercropping refers to cultivating more than one crop at a time arranged in a geometric pattern.

Internet of things (IoT) is the use of intelligently connected devices and systems to leverage data gathered by embedded sensors and actuators in machines and other physical objects.

Low-power wide-area network (LPWAN) is a wireless network technology that interconnects low-bandwidth, battery-powered devices with low bit rates over long ranges. Created for IoT networks, LPWANs operate at a lower cost with greater power efficiency than traditional mobile networks. They are also able to support more connected devices over a larger area.

Machine learning is a branch of artificial intelligence (AI) and computer science that focuses on the use of data and algorithms to imitate how humans learn, gradually improving its accuracy.

Mulching is the process of covering bare soil with a porous material to improve the condition of the soil underneath. It essentially creates a microclimate for plants to grow and perform better in an area that has regulated moisture content, suitable temperature, humidity, carbon dioxide and proper microbial activity within the soil.

Nature-based solutions are actions to protect, sustainably manage and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.

Nitrogen-fixing crops take nitrogen, an essential micronutrient for plant growth, from the atmosphere and add it to the soil after converting it into a plant-friendly form.

Normalized Difference Vegetation Index (NDVI) quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs).

Open data is information or content that can be freely used, modified and shared by anyone for any purpose.

Precision agriculture (PA) services that use farm-level data to customise advisory content, for example, drone imagery to identify problem areas in a field and identify appropriate interventions.

Regenerative agriculture is a holistic agricultural approach that retains or, if necessary, restores ecosystems to a healthy and resilient state by improving soils while also providing sufficient return to build up impact in different areas towards sustainability (environment, income, jobs).

Seed priming involves initiating the germination process before seeds are planted, resulting in higher germination rates and faster emergence of seedlings.

Soil spectroscopy is a method that has the potential to measure soil properties more rapidly and cost-effectively, both in the lab and in the field. Soil spectral analysis estimates soil properties by calibrating conventional reference measurements, such as wet chemistry soil tests, to the spectral signatures of soil captured by spectrometers.

Sustainable intensification is an approach using innovations to increase productivity without adverse social and environmental impact and without the conversion of additional non-agricultural land.

Urea is a natural product of nitrogen and protein metabolism and is predominantly found in urine and animal waste. It is a neutral, quick-acting fertiliser that is suitable for various soils and plants as a base fertiliser.

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