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DIGITIZING THE SCIENCE OF DISCOVERY AND THE SCIENCE OF DELIVERY

A Case Study of ICRISAT

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ABBREVIATIONS

BMS	Breeding Management System, a suite of software tools to manage breeding data throughout the crop improvement cycle.
CGIAR	Consultative Group for International Agricultural Research, a global partnership that unites organizations engaged in research for a food-secured future.
CIAT	International Center for Tropical Agriculture, a not-for-profit research and development organization dedicated to reducing poverty and hunger while protecting natural resources in developing countries.
EIB	Excellence in Breeding Platform
GOT	Government of Telangana
GSMA	GSM Association, an originally-European trade body that represents the interests of mobile network operators worldwide
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics, is an International organization which conducts agricultural research for rural development.
ICT	Information and Communication Technology, is a term which stresses the role of unified communications and the integration of telecommunications computers which enable users to access, store, transmit, and manipulate information.
ISAT	Intelligent Agricultural Systems Advisory Tool
IT	Information Technology, is the use of computers to store, retrieve, transmit, and manipulate data, or information, often in the context of a business or other enterprise.
KGS	Krishi Gyan Sagar, a tablet-based extension system.
MOU	Memorandum of Understanding, is a nonbinding agreement between two or more parties outlining the terms and details of an understanding, including each parties' requirements and responsibilities.
NGO	Non-Governmental Organization
PEAT	Progressive Environmental and Agricultural Technologies
SMS	Short Message Service, is a text messaging service component of most telephone, internet, and mobile-device systems.
3G	A mobile communications standard that allows mobile phones, computers, and other portable electronic devices to access the Internet wirelessly.
4G	a mobile communications standard that allows mobile phones, computers, and other portable electronic devices to access the Internet wirelessly

Author: Cristina Manfre and Wesley Laytham; July, 2018

This case study describes the digital agriculture work led by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), a CGIAR center based in Hyderabad, India. It is part of a series highlighting the integration of digital technologies into agricultural programs. Each case study examines different approaches to adoption and how digital tools impact organizational culture, operations, and programs.

EXECUTIVE SUMMARY

ICRISAT first began integrating digital tools into its research programs around 2009, but in 2014 digital agriculture became a critical component of the organization's mission to achieve scalable, sustainable, and equitable impact on the lives of smallholder farmers. ICRISAT launched a Digital Agriculture research theme and is now weaving digital tools across the organization's research and implementation work.

The need to achieve rapid and scalable impact for smallholders drives ICRISAT's approach. Each individual digital tool makes targeted gains to advance research or improve service delivery, and together they are ushering in a new digital era for agriculture in which ICRISAT and its partners can deliver "better, faster, and cheaper" technologies and services to empower smallholder farmers. ICRISAT uses digital agriculture interventions to:

Better serve farmers with digital tools that enable stronger connections between value chain actors and accelerate the transfer of research outputs and technologies to farmers. The Sowing App and Intelligent Agricultural Systems Advisory Tool (ISAT) deliver targeted and timely SMS messages to farmers about farm management practices, grounded in research, and the Plantix app helps extension officers automatically diagnose and respond to diseases and pests.

Forge impactful partnerships with a range of stakeholders who bring cutting-edge technology to agricultural research, extend ICRISAT's reach, and strengthen agricultural value chains. ICRISAT's approach in India involves working with state governments, local NGOs, CGIAR research programs, and technology innovators to achieve better development outcomes for farmers using digital tools. The iHub incubator connects technology innovators with ICRISAT researchers to catalyze innovations that can change agricultural research and the lives of farmers.

Improve the efficiency of work by improving the accuracy, timeliness, and cost of conducting research and of delivering agricultural research outputs to farmers, extension officers, the government, and other agricultural value chain actors. The LeasyScan allows researchers to rapidly measure leaf surface area and water stress and the HarvestMaster records highly accurate measurements of grain weight and moisture characteristics for development of new varieties.

Digital agriculture advances agricultural outcomes by driving more precise agriculture, better data collection and analytics, and more effective information dissemination. Although the organization's early successes with digital agriculture date back to 2009, the current wave of digital agriculture interventions will show significant impact in the coming years. The building blocks are in place and there is already evidence that ICRISAT's work leads to impacts that contribute to these outcomes in three ways:

1. **Providing better information and services to more farmers.** A better understanding of soil, forecasts, and climate variability helps farmers

make decisions about what crops to cultivate and what practices to adopt. Several digital interventions are providing farmers with better information for decision-making. Farmers who follows Sowing App advisories improved yields by an average of 30% and those who followed ISAT messages experienced up to 20% higher incomes. Many of ICRISAT's tools and approaches like the Sowing App and Plantix have been institutionalized into state government initiatives and are being scaled up across southern India.

2. **Strengthening connections between actors.** Digital agriculture interventions are closing gaps and strengthening connections between actors in agricultural value chains. The iHub itself plays a critical role in strengthening connections by encouraging technology start-ups to reconceive their products for the agriculture sector. Digital tools like Plantix and Kalgudi are creating two-way information flows between researchers and farmers and increasing transparency between actors.

3. **Transforming agricultural research for development.** Digital integration improves efficiency, accuracy, and traceability in research and implementation. The LeasyScan and HarvestMaster increase the speed and volume of highly accurate measurements and reduce costs per unit. ICRISAT breeding programs can model that data to predict yields for different varieties and prioritize traits to breed for. The result is a product development pipeline that is more accurate, nimble, flexible, and responsive to the needs of ICRISAT's clients. Digital agriculture is changing how scientists conduct research, and in the process unlocking opportunities to pursue new avenues of discovery.

Digital tools and approaches are becoming integral to how ICRISAT programs and their partners contribute to achieving the organizational mission. The case study provides further examples of the tools and approaches that are being piloted across the organization and how they will lead to increased impact. It concludes by highlighting valuable lessons for organizations wishing to pursue a similar digital integration.

DIGITIZING THE SCIENCE OF DISCOVERY AND THE SCIENCE OF DELIVERY

Series Overview: This case study is part of a series highlighting the integration of digital technologies into agricultural programs. Over the past ten years, and particularly over the past five, the use of mobile phones and Internet-based, digital tools in farming activities has skyrocketed. This is largely due to the widespread adoption of mobile phones in developing and emerging markets, coupled with the increased spread of 3G and 4G connectivity. What has emerged is a broad set of digitally-based applications that have driven greater financial inclusion, more precision agriculture, better data collection and analytics, and more effective information dissemination. Agricultural organizations and programs are increasingly embracing these tools to advance their goals. Each case study in this series looks at different approaches to adoption and how the tools are impacting organizational culture, operations, and programming.

OVERVIEW

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), a CGIAR research center (Box 1), is transforming its work. It is intentionally and explicitly harnessing the power of digital technologies to conduct research more efficiently and deliver agricultural research outputs to farmers, extension officers, the government, and other agricultural value chain actors. While it has been almost ten years since ICRISAT first began integrating digital tools into its research programs, in 2014 digital agriculture became a critical component of the organization's mission to achieve scalable, sustainable, and equitable impact on the lives of smallholder farmers in Sub-Saharan Africa and South Asia.

ICRISAT is creating a data ecosystem to drive the "Science of discovery to science of delivery," the organization's tagline. Digital upgrades in data collection and analysis in the crop breeding pipeline, for example, are improving the accuracy and efficiency of the science of discovery. It is changing how scientists conduct research; shifting time spent on data collection to data analysis, and in the process unlocking opportunities to pursue new avenues of discovery. Digital tools are also enabling stronger connections between value chain actors and accelerating the transfer of research outputs and technologies to farmers. Each individual digital tool is making targeted gains to advance research or improve service delivery. Together the tools and technologies are ushering in a new digital era for agriculture in which ICRISAT and its partners can deliver "better, faster, and cheaper" technologies and services to empower smallholder farmers.

"Digital Agriculture is 'ICT and data ecosystems to support thedevelopment and delivery of timely, targeted information and services to make farming profitable and sustainable while delivering safe nutritious and affordable food for ALL.'"[1]

This case study shows how digital tools are changing the organizational culture of ICRISAT. It begins with an overview of the digital landscape in India. It then describes ICRISAT's digital agriculture approach and specifically its experience integrating various digital

1 ICRISAT. 2016. Digital Agriculture: Pathway to Prosperity. http://www.icrisat.org/wp-content/uploads/Digital-agriculture-flyer.pdf

tools and approaches in its programs, with a special focus on India. It provides insight into the impact of digital agriculture on ICRISAT's operations and work with partners and farmers. Finally, it offers lessons learned about its digital integration experience drawn from the reflections of staff, partners, and other stakeholders.

THE DIGITAL LANDSCAPE

ICRISAT works across the dryland tropics in South Asia and Sub-Saharan Africa to reduce poverty, hunger, malnutrition, and environmental degradation through a focus on crops that survive in harsh climates. The mandate crops include legumes, like chickpea, groundnut, and pigeon pea, and nutri-cereals, like sorghum, pearl millet, and finger millet. For this case study, interviews were conducted with staff at the center's headquarters in Hyderabad, India and with other stakeholders involved in research activities in Telangana and Andhra Pradesh states. While ICRISAT's digital agriculture work is integrated in its programs across South Asia and Sub-Saharan Africa, the convergence of both national and state level digital

BOX 1
SITE-SPECIFIC AGRICULTURE

The CGIAR, formerly known as the Consultative Group for International Agricultural Research, is a "global research partnership for a food-secure future." It is made up of 15 CGIAR research centers, of which CIAT is one, that collaborate with national agricultural research centers, civil society organizations, development organizations, and the private sector to advance the science to reduce poverty and malnutrition, enhance food security, and improve natural resource management. The CGIAR's mission is, "to advance agricultural science and innovation to enable poor people, especially women, to better nourish their families, and improve productivity and resilience so they can share in economic growth and manage natural resources in the face of climate change and other challenges."

Source: www.cgiar.org

investments in India create a unique landscape for piloting and scaling digital agriculture initiatives.

Although India's workforce is largely involved in agriculture, nearly 54.6% of the workforce and 60% of rural households according to the 2011 census, its economy has been marked for many years by a large services sector tied to information technology (IT) and business outsourcing (FAO 2017; Government of India 2017). The most recent data from 2015-2018 reveals that while the country has a competitive mobile phone environment, with 10 active mobile phone operators, onboarding India's population of 1.3 billion remains a challenge (GSMA Intelligence). In 2015, the country recorded 1 billion connections, equivalent to about 76% of the population, yet the unique subscriber penetration was only 36%, and only 15% of connections were broadband (GSMA Intelligence; GSMA 2015). Furthermore, research by GSMA reveals a higher than average gender gap in mobile phone ownership, with an estimated 114 million fewer women than men owning a phone (GSMA 2015). By 2018 unique subscriber penetration rose to 53%, but a 23% gender gap in mobile phone ownership remained (GSMA 2018; GSMA Connected Women 2018). Even among men and women owners however, usage remains low: only 46% and 31% of men owners report sending an SMS and using mobile internet respectively (GSMA Connected Women 2018). The percentages are lower for women mobile phone owners, with 34% reporting sending an SMS and 13% using mobile internet (GSMA Connected Women 2018). Handset cost remains a barrier for both men and women while technical literacy and confidence in using technology further constrain women's uptake and use.

BOX 2

BHOOCHETANA (2009-2012)

Bhoochetana was an integrated watershed management project developed by ICRISAT, the Karnataka Department of Agriculture, and local universities. It reached 4.75 million people. Farmers increased productivity by 20-60% and the agriculture sector grew by USD 353 million. Several digital tools supported these impacts:

Digital soil health maps were created and posted online for 3.7 million hectares of land. These maps were a valuable resource that induced the Government of India to commit to mapping soil health for all farms by 2019. The maps provided background data necessary for some of the other digital tools described in this case study.

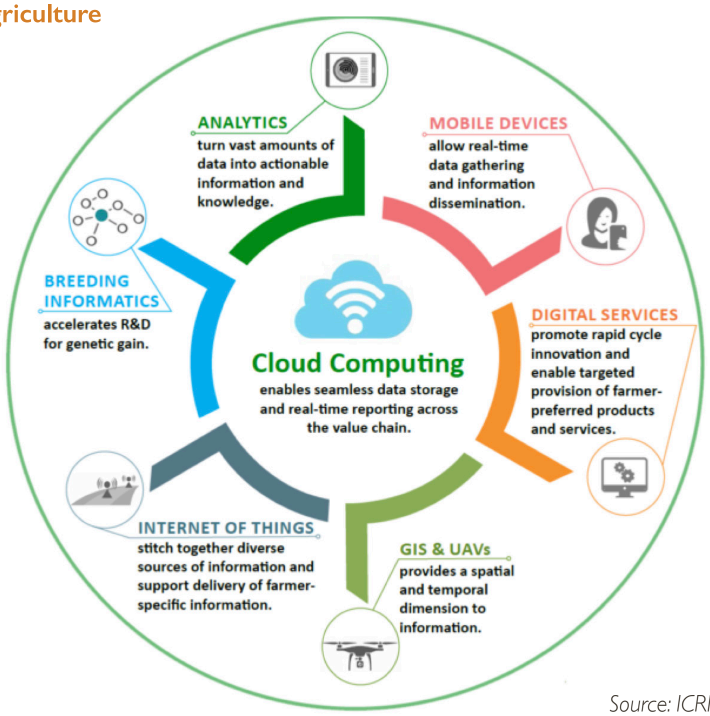
In collaboration with Digital Green, farmer facilitators were trained to develop and share localized knowledge with farmer-to-farmer videos. The videos are recorded locally and screened for small groups. In Karnataka, 48% of those who viewed videos reported adopting new technologies.

Krishi Vani provided free voice messages to 40,000 farmers using a "green sim." Weekly messages covered 16 categories like weather, markets, crops, and nutrition. Krishi Vani was created in partnership with Airtel and IFFCO Kisan Sanchar Ltd. and was piloted in 171 villages in Karnataka and Telangana.

Krishi Gyan Sagar (KGS), a tablet-based extension system, provided personalized advisories to farmers based on data input. KGS expanded into Andhra Pradesh and Telangana after a pilot in Karnataka.

Source: Wani et al. 2013; ICRISAT 2016

Figure 1: Digital Agriculture



Source: ICRISAT Digital Agriculture flyer

In part to change the status quo, in 2015, Prime Minister Modi announced the Government of India's Digital India initiative, "to transform India into a digitally empowered society and knowledge economy." The initiative aims to improve digital infrastructure, enhance online delivery of services, and increase digital literacy. Its programs are expanding rural connectivity, for example through partnerships with Google, Facebook, and Microsoft. Both national and state-level government services are moving to online platforms and applications to improve and streamline service delivery. The state of Andhra Pradesh, for example, has digitized all of its land records and created two portals for accessing them: Webland, used by the revenue administration and Mee Bhumi, created for individuals to view their land details and associated loan applications (Melly Maitreyu 2015). Andhra Pradesh and neighboring Telangana are now in the process of incorporating blockchain technology to record and secure land records and other citizen registries (Das 2017). Major metropolitan areas are attracting new investment from technology companies and at the same time expanding opportunities for IT professionals and innovators. Hyderabad, in the state of Telangana and where ICRISAT is located, is now considered to be India's most important technology hub. Microsoft, Qualcomm, Amazon, and Google have established offices there and others are following quickly. It hosts the T-Hub, a start-up incubator established in 2015 to provide mentorship, workspace, and workshops to early and growth stage companies (Ranipeta 2017). The Government of Telangana (GOT) continues to seek opportunities to expand the use of digital tools and attract cutting-edge information technologies: in early 2018 Nasscom and the GOT were in discussion about establishing a Center of Excellence for Artificial Intelligence and Data Sciences (The Hindu 2018).

While this digital landscape is not focused exclusively on agriculture ICRISAT is using its fortuitous location to tap local talent, develop partnerships, and leverage existing investments to further its aim to deliver better, faster, cheaper digitally enabled services. Furthermore, the organization's commitment to identifying transformational solutions for women and youth position it to set an example for how to ensure digital solutions are equitable solutions.

APPROACH TO DIGITAL INTEGRATION

In 2009, researchers embarked on one of the first successful digital integration experiences at ICRISAT. The Bhoochetana program in Karnataka used a suite of digital tools to support the achievement of productivity and livelihood outcomes for farmers (Box 2). ICRISAT scientists saw the benefits of digital tools for specific research purposes like in Bhoochetana, but digital tools were not mainstreamed throughout research programs and were seldom used to disseminate findings.

A new Director General, David Bergvinson, arrived in 2014 and pushed the organization to fully embrace digital integration. ICRISAT launched a Digital Agriculture research theme and is weaving digital tools across the organization, from breeding and extension to M&E (Figure 1). ICRISAT leverages its position as a premier agricultural research institution to harness diverse digital expertise for its agricultural research. The approach to digital agriculture is driven by the need to achieve rapid and scalable impact for smallholder farmers in Sub-Saharan Africa and South Asia.

This means:

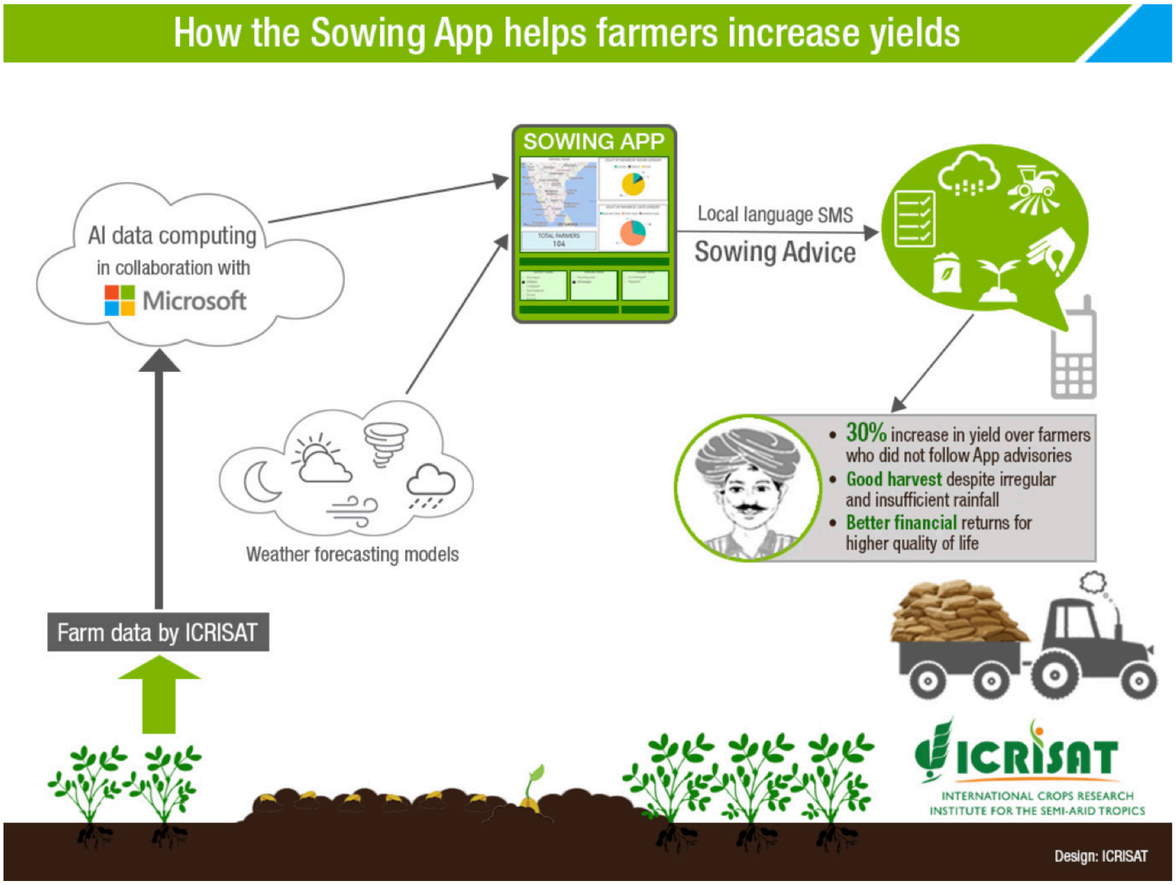
- Identifying the most promising tools to **serve farmers;**
- Forging **partnerships** with stakeholders who can bring cutting-edge technology to agricultural research, extend ICRISAT's reach, and strengthen agricultural value chains; and,
- Improving the **accuracy, timeliness, and cost** of discovering and delivering agricultural technologies to small-scale farmers.

The digital technologies highlighted below exemplify ICRISAT's digital approach. While not all encompassing, the highlighted tools and technologies illustrate how ICRISAT is using digital tools to better serve farmers, forge impactful partnerships, and improve the efficiency of its work. Table 1 provides a snapshot of digital interventions that are described in this section explaining the purpose of the digital intervention and where it fits in the agricultural value chain.

Table 1: Summary of Digital Agriculture Interventions

DIGITAL AGRICULTURE INVESTMENT	PURPOSE OF THE TOOL	VALUE CHAIN STAGE
Sowing App and Intelligent Agricultural Systems Advisory Tool (ISAT)	To deliver targeted and timely SMS messages to farmers about sowing and other farm management practices	On-farm production
iHub	An incubator program and platform to catalyze technology innovations that can change the lives of farmers	Cross-cutting
Plantix	To provide extension officers with automated and targeted responses about diseases and pests through a mobile app	On-farm production
LeasyScan	To rapidly measure leaf surface area characteristics and water stress and accelerate the identification of promising new varieties	Planning
HarvestMaster	To record highly accurate measurements of grain weight and moisture characteristics for development of new varieties	Planning

Figure 2: Sowing App



Sowing App and the Intelligent Agricultural Systems Advisory Tool (ISAT): Most dryland farmers in India practice rainfed agriculture. In the face of shifting monsoon patterns, increasingly frequent dry spells, and other climate variability factors, farmers who do not adapt their agricultural practices experience lower yields and increased losses. Many farmers however do not have access to accurate climate and weather information and make decisions based on their own historical knowledge.

ICRISAT developed two different tools to provide farmers with timely and targeted information about when to sow and what management practices to adopt. The **Sowing app** uses cloud-based predictive analytics tools on Microsoft Azure including Cortana artificial intelligence and machine learning to predict an optimal sowing period and other farm management practices (Figure 2). The **Intelligent Agricultural Systems Advisory Tool (ISAT)** integrates historical climate data, seasonal and short-term weather forecasts, soil information, and crop models to create decision trees with recommended actions for farmers.[2] Both tools address these challenges by delivering SMS messages to farmers about when to sow and what management practices to adopt personalized to their village soil profile and weather forecast.

The tools were developed and are being piloted in partnership with different actors. The Sowing app is a partnership between ICRISAT, Microsoft India, and the Government of Andhra Pradesh. It was piloted in

2 ISAT decision trees are based on a proven Australian decision support tool called Yield Profit.

2016 in seven villages in Devanakonda mandal, Kurnool district and targeted 175 groundnut farmers working with local NGO Chaithanya Youth Association.[3] The Sowing App is currently being scaled up in 13 districts of Andhra Pradesh (Bossuet 2017). The ISAT pilot is in its second year and focuses on 700 groundnut farmers practicing rainfed agriculture in sandy soils with low rainfall. ICRISAT collaborates with Microsoft, local universities, and extension providers to downscale rainfall data, develop and validate recommendations, and engage with farmers. Currently, all SMS messages are cross-posted in a third-party app, expanding the reach of ISAT beyond the 700-farmer pilot (Box 4).

BOX 3

KALGUDI

Kalgudi is a free online platform developed by Vasudhaika Software Solutions for producers, traders, service providers, and others. Users post and answer questions, access news and agricultural recommendations, and make market linkages, all in their own language.

Kalgudi provides an opportunity for ICRISAT to rapidly deliver trustworthy information like the weekly ISAT messages or pest alerts to more farmers. Researchers can analyze how users interact with posts to see what is popular, if users disagree with information, and what additional material users want.

Representatives from Mulkanoor Cooperative and Swarkrushi FPO shared that Kalgudi has encouraged a culture of curiosity in agriculture. Kalgudi provides information about topics that before they knew "nothing" about. Farmers trust the information because it is in their local language and provided by reputable sources, including ICRISAT. Still, smallholders have a low tolerance for risk. Members reported that one person tests a new advisory, and if it succeeds more farmers will adopt a recommendation for farming decisions. Widespread use of Kalgudi would allow ICRISAT researchers to reach many more farmers with time-sensitive information.

Source: www.kalgudi.com and interviews

iHub: The iHub is an incubator program at ICRISAT that that provides mentorship for agricultural technology start-ups to improve research programs and accelerate the science of delivery. The Digital Agriculture team launched the iHub in February 2017. The iHub is an innovation broker that creates partnerships between technology innovators and ICRISAT research programs. It connects entrepreneurs with mentors to help improve and iterate on innovations to meet needs across value chains and lead to social and economic impacts for farmers.

There are currently twelve entrepreneurs in the iHub whose innovations create efficiencies in research, reduce costs, and improve farmer outcomes. Some, like Plantix, help reduce farmer uncertainty and collect new observational data that can improve and target research. Others, like Kalgudi, create feedback loops between farmers and researchers (Box 3). Collaboration encourages more interdisciplinary research and can improve the product development pipeline with complementary expertise.

3 This work is part of Rythu Kosam, the Andhra Pradesh Primary Sector Mission project.

Plantix: When crop health deteriorates, smallholders do not always know the reason or have an effective response, particularly when the cause is an uncommon pest or disease. Overtaxed extension systems are challenged to provide smallholders with the right information when they need it and farmers experience crop losses. In November 2016, ICRISAT and the government of Andhra Pradesh signed an MOU with PEAT to pilot Plantix at scale.[4]

Plantix is a free mobile crop advisory app developed by German start-up Progressive Environmental and Agricultural Technologies (PEAT). The app uses machine learning for automated image recognition that diagnoses over 240 plant diseases, pests, and nutrient deficiencies. An offline library details 400 total types of crop damage. Once Plantix identifies a plant damage, it returns simple information on symptoms, triggers, controls, and preventative measures in English, Hindi, Telugu, or five other languages. The pilot targets government extension agents because of limitations in smartphone ownership and the opportunity to reach more total farmers through intermediaries.[5] There are roughly 6,500 extension agents in Andhra Pradesh and each is responsible for a 5,000-hectare target area.

ICRISAT researchers and partners provided locally relevant content that was critical for adapting Plantix to dryland crops and plant damage. ICRISAT staff worked extensively with research stations and agricultural universities to sensitize and train more than 3,500 students and staff on the app. To build the local image database, the consortium used open source images from PlantVillage,[6] universities, research centers, and hired "picture hunters" to upload photos from around India. Experts from 18 universities tag the photos and train the image recognition algorithms. As of December 2017, the database houses nearly two million images and successfully identifies common diseases in India more than 90% of the time. The app also includes a community feature for users to engage with each other and experts in local and global channels. Recently, the app added regional forecasts which are important for understanding the vitality of a pest or disease, or the effectiveness of a recommended control method.

LeasyScan: The LeasyScan phenotyping platform automatically measures important characteristics related to leaf surface area and water stress for large quantities of plants. In the wake of a revolution in genomic tools driven by advances in technology, high throughput and precision phenotyping became a significant bottleneck for plant breeding (ICRISAT GEMS 2016). Prior to the LeasyScan, ICRISAT scientists cut and physically measured leaves to observe these characteristics. This process was slow and destroyed the plant, hindering comparison throughout an entire growth cycle. Hand measurement also introduced opportunities for inconsistencies and error within and across breeding programs at ICRISAT.

ICRISAT collaborated with Phenospex in 2014 to adapt their scanner technology for high throughput phenotyping trials. The LeasyScan uses eight laser triangulation scanners and scales to create a database of 3D plant images and weights for up to 4,800 plants multiple times a day. The scanners are mounted on an irrigation boom that moves over experimental units without touching the plants, keeping them intact for comparison over time. This is quicker than other

4 PEAT is also being incubated in the iHub.
5 Most households in Andhra Pradesh own a smartphone, but farmers are not accustomed to using them on farms.
6 PlantVillage is a free, open access crop health platform run by Penn State University.

automated techniques that move plants through a stationary scanner at a much lower throughput (Vadez et al. 2015). Measurements from the LeasyScan are comparable to conventional measurements across multiple crops. Each plant is also barcoded, so phenotyping teams can link qualitative observations of individual plants with database records to inform breeding decisions. Using the database, researchers extract simple, ready-to-use data about plant growth and transpiration to help select stress-tolerant germplasm for the development of improved varieties.

HarvestMaster: The HarvestMaster is a grain gauge originally developed for use on combines in the 1980s. The device measures plot weight, test weight, and harvest moisture. In 2017, under the phenotyping module of the CGIAR Excellence in Breeding Platform (EIB), ICRISAT began using a standalone HarvestMaster for digital data collection to accelerate the breeding pipeline. The model at ICRISAT can be mounted in the bed of a pickup truck and deliver high-quality measurements in field conditions. An integrated tablet stores and transfers data from the HarvestMaster. The portability of the HarvestMaster shortens the process of aggregating and measuring grain, which previously took 3-6 months. By speeding data collection, phenotyping teams can make decisions about the next season earlier and accelerate the entire breeding process. They can also standardize the measurement of grain across all ICRISAT breeding stations which will improve comparisons of different grain varieties grown in different conditions. Longterm, ICRISAT scientists intend to add sensors to the HarvestMaster to track other parameters like those related to micronutrients and nutrient density. This can help breeding programs identify high-nutrition grain that also meets other crop development criteria.

UNDERSTANDING THE IMPACT OF DIGITAL TOOLS

ICRISAT's investments in digital agriculture will fundamentally change how it operates. By harnessing the power of technology, it will be able to discover and deliver agricultural research outputs to farmers more rapidly and at scale. Although the organization's early successes with digital agriculture date back to 2009, the current wave of digital agriculture interventions will begin to show significant impact in the coming years. Many of the building blocks are now in place and researchers are already benefiting from dramatic shifts in how they spend their time. The impact on farmers, in terms of access to new seeds and other technologies, is also on its way. There is already evidence from several digital agriculture interventions that they are positively impacting farmer outcomes, and this will likely continue as more digital tools are integrated and programs scale. The more significant changes at the moment are within the organization as different teams become familiar with how digital technologies can improve their work and enable them to explore new avenues for research.

The investments in digital data collection and management systems are a critical component of the organization's digital transformation. Two systems have been introduced improve the efficiency and accuracy of data collection: 1. the Breeding Management System (BMS), a suite of software tools to manage breeding data throughout the crop improvement cycle; and, 2. a standard monitoring and evaluating system for programs. These investments allow researchers and scientists to shift time from paper and pen data collection to data analysis and action. Together, they will vastly improve the organization's ability to monitor in real-time, capture impact, and inform planning and strategy.

This section outlines the changes and achievements stemming largely from the digital interventions highlighted in the approach section. It identifies where digital agriculture interventions have led to positive outcomes for farmers, primarily in targeting information delivery, and highlights the potential impact of other technologies, and how the organization itself is changing.

PROVIDING BETTER INFORMATION AND SERVICES TO MORE FARMERS

A better understanding of soil, forecasts, and climate variability helps farmers make decisions about what crops to cultivate and what practices to adopt. During the Sowing App pilot, researchers recommended that farmers delay planting from the first week of June to the last week. When a dry spell occurred, crops sown during the recommended window recovered from the moisture stress better than those sown at the normal time. According to ICRISAT, farmers who followed Sowing App advisories experienced an average yield increase of 30% compared to farmers who did not delay their planting (ICRISAT 2017a; ICRISAT 2017b).

While the first year of the ISAT program does not have impact data, evidence from earlier projects using components of the ISAT show that farmers who followed recommendation experienced up to 20% higher income than farmers who did not (Bossuet 2017; ICRISAT 2016). There is also anecdotal evidence from the team that farmers followed the recommendations. In the first year of the pilot day-labor prices increased during the optimal sowing week, indicating farmers chose to plant according to the recommendation. In 2018 the team will measure the impact of messages against a control village.

Similarly, the economic benefits of Plantix for farmers has not been quantified. However, Plantix has grown popular as a result of the ICRISAT pilot, being promoted by the Government of Andhra Pradesh, press coverage, and word of mouth. A Telugu version launched in May 2017 and use significantly increased in Andhra Pradesh and Telangana. In November 2017, Plantix was the 9th most popular app in the Education category of the Google Play store for India. The organic growth of the app shows that farmers value tools that help fill gaps in extension services and knowledge. ICRISAT programs may be able to scale Plantix into other countries with chronic plant damage and underdeveloped extension systems as smartphone costs continue to decrease and mobile data coverage improves.

The demand to scale many of the digital interventions is not limited to Plantix. There is increased evidence that farmers and state governments value the information delivery tools that enhance extension services. Farmers in the Sowing App pilot reported sharing recommendations with others in the community. This led to increased demand for the Sowing App. After seeing the benefits, many more farmers want to participate. The initial pilot was limited to 175 farmers, but now the app is scaling up to serve more than 2,000 farmers across 13 districts in Andhra Pradesh. The Governments of Andhra Pradesh and Telangana have incorporated the Sowing App into state programs, and recently the Government of Karnataka also signed an agreement with Microsoft and ICRISAT to scale up the approach.

STRENGTHENING CONNECTIONS BETWEEN ACTORS

Many of the digital agriculture interventions are closing the gap and strengthening the connections between different actors in the agricultural value chain. Digital technologies are doing this in a number of ways by creating two-way information flows between researchers and farmers and by increasing transparency between actors. Digital tools, like Plantix, and information platforms, like Kalgudi, allow farmers to connect directly with subject matter experts. At the same time, these platforms enable researchers to engage with farmers more directly, allowing them to better understand the farmer's needs and to validate research recommendations.

Other technologies, like the HarvestMaster, have the potential to increase transparency across the value chain. While the HarvestMaster is currently only being used by ICRISAT in a research context, the beyond-research applications are clear. Farmers often feel cheated by traders, and many are, because they lack information about the quality of their grain and how market prices respond to different standards. The HarvestMaster could dramatically increase the bargaining power of farmers by providing rapid feedback about the quality of grain. It is portable and therefore can be installed at grain aggregation points where farmers and buyers trade, which could increase trust between these two actors.

The iHub itself plays a critical role in strengthening these connections by encouraging technology start-ups to reconceive their products for the agriculture sector. Some of these start-ups, like Keansa Solutions and Kalgudi, have experience with supply chains but are now specifically thinking about farmers and farmer producer organizations as among their target users. Similarly, Aheadrace, a Hyderabad-based startup, is exploring how to adapt its online learning tools to build knowledge among farmers and extension officers. This is made possible by creating a space for innovators and researchers to bring their respective expertise together to support agricultural development outcomes. This has not been easy, and the iHub team acknowledges that they are a surprising addition to the ICRISAT research organization. At first, some scientists saw engagement with iHub incubatees as an additional time burden, while there was a sense that others felt it challenged their expertise. A year into the program however, scientists are seeing the value that the incubator provides to research programs by introducing new tools to them and enabling them to envision new application for their agricultural expertise.

TRANSFORMING AGRICULTURAL RESEARCH FOR DEVELOPMENT

Digital agriculture is changing how ICRISAT research programs support smallholder farmers. As described by the Director General, digital agriculture offers a huge return on investment when done strategically. Researchers highlight improved efficiency, accuracy, and traceability as key ways that day-to-day operations are changing because of digital tools. These changes support shifts in research programs that create an implementation approach and product development pipeline that is more nimble, flexible, and responsive to the needs of ICRISAT's end-user clients.

Some digital tools like the LeasyScan and HarvestMaster dramatically increase the speed and volume of measurements. When phenotypic and genomic data are integrated, researchers can identify and select genetic markers for promising traits sooner, which leads to a faster and more targeted crop improvement pipeline. While breeding will still take six generations, the workload within a season is greatly reduced. As put by one scientist, "in breeding, time matters." Some digital

tools, like the LeasyScan, reduce measurement costs per unit, dramatically increasing the volume of genetic material they test. Other digital tools create efficiencies by bypassing or simulating certain steps. Crop models can use LeasyScan and HarvestMaster data to help ICRISAT researchers predict yields for varieties in different conditions, capturing more seasonal variability than multi-location trials. Teams can prioritize traits to breed for in an agroecological zone without testing each variety, saving time and money by only testing the most promising varieties. And while many digital tools have a high initial cost, they are recovered over time through improvements in efficiency. In the case of the HarvestMaster, which costs USD 15,000, ICRISAT researchers estimate that the cost will be recovered within two years. The phenotyping team is exploring the use of alternative sensors to further reduce the unit cost.

The Nutri Food Basket pilot is using tablets for a baseline and daily monitoring of food supplement distribution and consumption in Telangana government Anganwadi centers.[7] Using digital tools, the team is able to track attendance and consumption of the food supplements using barcoded food packages: they can monitor how many (and to whom the) packages have been distributed and opened at the centers. The traceability feature enabled with the bar coding also allows the team to recall specific packages in the instance of contamination, a benefit that was discovered in 2017. When the team realized that a certain batch of supplements was contaminated, they were able to track where those packages were and recall them within an hour. Lessons from the Nutri Food Basket pilot, particularly around the benefits of digital data collection, have been incorporated into a similar project in Bangladesh where the tools allow for close monitoring of data and rapid correction of enumerator mistakes with coaching, despite geographic distance (ICRISAT 2017c).

7 These rural centers provide basic health care, nutrition education, and other services to women and children.

LESSONS LEARNED

This section outlines lessons learned from the experience of ICRISAT and partners with the digital tools highlighted earlier in this case study. It is organized around the Principles for Digital Development; a set of principles developed by donors and the development community to guide and inform technology-enabled development programs.[8] The discussion below includes the most significant reflections and therefore not all of the Principles are represented.

PRINCIPLE TWO: UNDERSTAND THE ECOSYSTEM

India offers a great analogue for many countries in which ICRISAT works. Its large number of farming families, estimated at 137 million, and degraded environments drives a mandate to rapidly develop cost-effective and impactful solutions to agricultural development. Unlike other countries however, India's technological landscape offers the additional opportunity to test how digital technologies can accelerate the discovery and delivery of research outputs.

The digital landscape, and particularly the fast-growing technology hub that is Hyderabad, allows ICRISAT researchers to engage in digital networks and communities. The iHub exemplifies how well the organization understands its ecosystem by creating a space for agricultural researchers and technology innovators to interact and challenge each other to drive better solutions and products. Research programs are designed to deliberately connect to digital initiatives implemented by state governments, particularly in Andhra Pradesh, Karnataka, and Telangana, and align with national goals and objectives.

While India affords many benefits, the transfer of technology to other countries where ICRISAT works requires adaptation to different digital landscapes. In Senegal, for example, there was an attempt to introduce drones for image capture, but the weak internet connection made it difficult to transfer data.

PRINCIPLE FIVE: BE DATA DRIVEN

Digital data and cloud computing are at the center of ICRISAT's digital agriculture initiative. Digital data collection and analytical systems allow for real-time reporting and the ability to interpret data into actionable information. It also enables the exploration and analysis of new research questions. ICRISAT's investments to modernize its M&E and breeding management systems are examples of this principle.

Many teams are new to digital data collection and analysis, which has at times meant that staff have not properly planned for or understood the potential of digital systems. In the case of the Nutri Food Basket project in India, the team had not planned to use digital tools for data collection but now see that their work would not have been possible without them because of the short timeframe and scale of the project. Their experience has also opened their eyes to new avenues for research and analysis. For example, with geotagging, the team could examine

8 http://digitalprinciples.org/

how the distance between households and the Anganwadi Center affects the participation of women and their children in the program. This could provide valuable information to the State governments about where to locate new centers.

Even with expanding research opportunities, operational challenges remain. Initially the LeasyScan team was overwhelmed by the quantity of information - roughly 500,000 data points a day and terabytes of 3D images – but they have since improved the data management systems.

PRINCIPLE SIX: USE OPEN DATA, OPEN STANDARDS, OPEN SOURCE, OPEN INNOVATION

In 2013, the 15 centers of the CGIAR made a commitment to disseminate and make available their research results, data and databases, and other information products (CGIAR 2016). This pushed many of the centers, including ICRISAT, to focus on data quality and seek more efficient ways to clean, manage, and store data. If researchers were going to be held accountable for sharing their data, then it was important the data be of good quality, with as few errors as possible. The best way of achieving this was to incorporate digital data collection tools where errors, when they do appear, at least are more predictable and consistent than human errors. This also had the result, as one researcher reflected, "of pushing data out into the open." In many cases, data was "hidden" in project reports, in a file, and on people's computers. The commitment to open data made this information public.

However, arriving at a place where data and databases can be shared takes some work, as many researchers reflected. And it's not just about the data collection or management software but data standardization. In many cases this means upfront investments to standardize naming conventions and ranges or values for prepopulated surveys. Ultimately these discussions and practices save time when researchers and technicians are in the field and can quickly find their trials and enter data. Additionally, Abhishek Rathore, the theme leader for Statistics, Bioinformatics & Data Management, highlights that "the system [now] has data integrity built into it." Nonetheless, migrating to a new system requires the willingness and patience to agree upon and create standard protocols.

Just because the data is now more available, it doesn't mean we can share it right away.
– Padmaja, Senior Scientist - Gender Research

PRINCIPLE SEVEN: REUSE AND IMPROVE

One of the most common themes that emerged during interviews with ICRISAT staff was a commitment to reusing and improving existing digital tools and technologies. Early on the organization invested in building their own systems but quickly realized that it was not advantageous for the size and scope of ICRISAT to develop its own digital platforms. What worked better was outlining their needs and problems and then identifying available technologies and partners with whom technology could be adapted, modified, and extended, a process familiar to agricultural researchers and scientists.

While looking for a faster way to measure plant growth, Vincent Vadez, who leads the LeasyScan work, explained that he drew inspiration from companies using imaging tools to measure plant size. In the Netherlands the horticulture industry uses scanners to measure the height of plants to make sure their produce will fit on supermarket shelves. Working with a manufacturer of these scanners, Vadez and his team developed the LeasyScan to measure leaf surface area, as well as plant height and operate in environments with higher light intensity. Similarly, over the course of one year, ICRISAT researchers worked with the HarvestMaster manufacturer to modify the technology into a standalone, portable unit.

PRINCIPLE NINE: BE COLLABORATIVE

ICRISAT has a long history of collaboration which now extends to its digital agriculture work. The organization established the Agribusiness and Innovation Platform in 2003 to build public-private partnerships that can enhance technology transfer and commercialization. This continues today and is complemented by the iHub, which focuses more explicitly on digital ventures, as well as partnerships with the private sector to develop cost-effective and time-saving technologies, like the LeasyScan and the HarvestMaster. Other examples include the mobile extension service, Krishi Vani, a collaboration between IFFCO Kisan Sanchar Limited and Bharti Airtel, and the mobile climate delivery service in Ghana developed with Esoko Networks and the Ghana Meteorological service. In India in particular, ICRISAT's work intentionally plugs into state and local governments, agricultural universities, and extension systems. These partnerships represent a commitment to finding sustainable locally-owned solutions.

Don't try to build a system. The world is moving from building systems to procuring a service as a system. [If you build a system] you will end up focusing on developing [it] and not implementing [the system]. [You should] get whatever is available and customize it to your need.
– Satish, Manager - Digital Agriculture

CONCLUSION

Digital agriculture is changing the standard for how research programs at ICRISAT operate. Many programs have used some aspect of digital tools over the past ten years, but only in the last three years has digital integration become a major focus across the organization. Now digital integration is seen as a way to reduce research costs while increasing the accuracy and relevance of information, to ultimately improve agricultural outcomes for smallholder farmers. Digital tools and approaches are becoming integral to how ICRISAT programs and their partners contribute to achieving the organizational mission.

New digital tools and approaches shift how researchers view what is possible in agricultural research. They can use digital agriculture to leverage research programs to focus on the expressed needs of farmers. Some of the new digital agriculture approaches have already led to impact and are being scaled up across India and into other ICRISAT focal countries. Other digital tools, like those in the iHub, have just recently been put in place, but are positioned to revolutionize how ICRISAT does the science of discovery and the science of delivery. Now, after the maturation of these tools and systems, ICRISAT programs are at the precipice of understanding the full potential offered by digital agriculture.

For example, ICRISAT researchers can use the geotagged Plantix database to help predict and prevent crop damage. Predictive models could analyze the incidence of crop damage to determine the conditions that intensify or spread a pest or disease. Researchers could develop more resistant cultivars or better control measures, governments could tailor support based on the likelihood of an outbreak, and insurance providers could offer products tailored to the needs of smallholders. The LeasyScan database of 3D images is a potential treasure trove of data for research. As analytical software improves, ICRISAT researchers may be able to learn more about specific plant organs for future breeding (Vadez et al. 2015). The team envisions a future when the datasets may be made open access for additional analysis by the wider community. They can also use digital-driven advancements in phenotyping to help overcome adoption barriers for improved varieties. The LeasyScan and HarvestMaster can enable researchers to identify consumer-desired traits related to taste or cooking that encourage adoption of improved varieties. The next several years will show how investments in digital integration can accelerate and streamline agricultural research and improve the timeliness and quality of cultivar and information delivery to smallholder farmers.

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