The 2017 CGIAR Inspire Challenge

Innovation strategies for digital agriculture

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Summary

Global agriculture is increasingly driven by data. Advances in computing power, data storage, and data communications over the last 30 years have given rise to powerful tools for helping make farming and food systems more precise, profitable, and adaptive. Newer digital innovations -- including machine learning, the expansion of connected sensor technologies, and robotics -- promise more dramatic changes in the farming landscape in the near future.

However, digital agriculture worldwide has not realized its full potential. Despite very active promotion from industry, to date, the real rates of adoption of precision agriculture have been slow in most industrialized economies, where market offerings tend to favor large farms or high-value specialty crops.[1] Farmers, and those who serve them, must navigate an array of competing standards for equipment and services. Farm data ownership and, as a result, the best way forward for the free flow of data, remains unclear.[2]

In developing economies, digital agriculture technologies have found even less of a foothold. Recent World Bank research in Kenya, Senegal, South Africa, and Armenia found that telecommunications companies, value added service providers, application developers and other actors in the mobile application ecosystems of these countries perceived the agricultural sector to be the least impacted by digital technology and well behind other economic sectors.[3] Only five of the 73 digital technology firms surveyed identified the agricultural sector as a source of potential revenue. AgFunder's 2017 *AgriFood Tech Investment Report* notes the overall rate of seed funding for startups has slowed, despite the existence of numerous technology accelerators and incubators worldwide. This does not bode well for the future of digital innovation in this sector.[4]

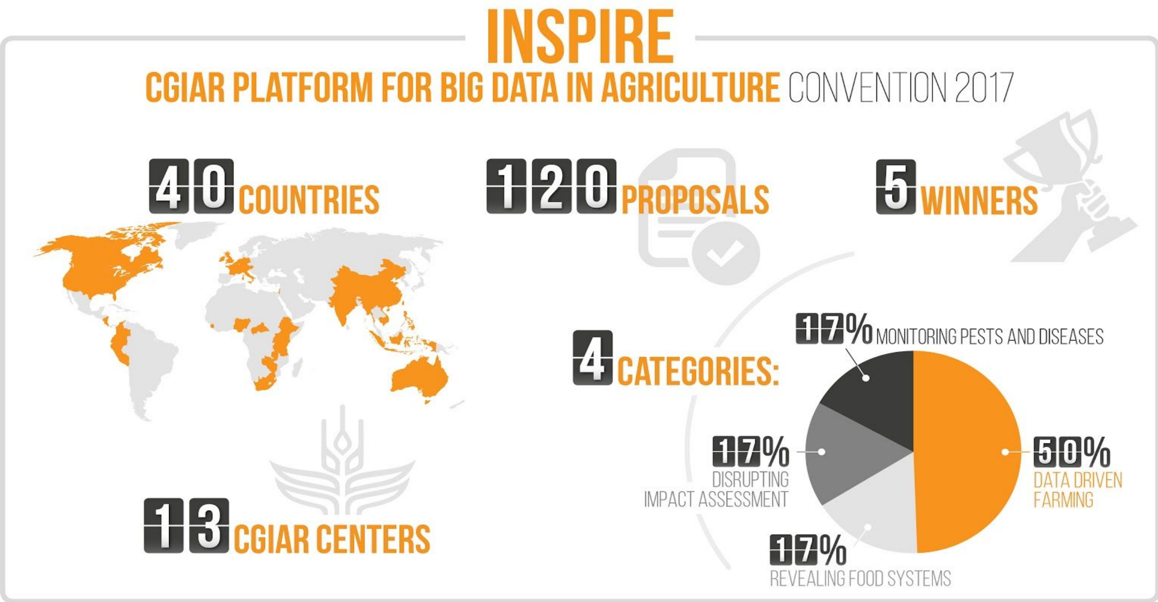
Innovation in emerging economies may still prove to be the catalyst that moves global digital agriculture forward. There is no lack of processes and places created to foster digital innovation in developing economies, yet, rarely do these digital innovations find a foothold and a path to scale in the agriculture sector. In order to address this gap, the sector needs to learn more about the factors that, in aggregate, can be managed to help digital innovation in agriculture move from proof of concept to successful

[1] "Adoption of Precision Agriculture," United States Department of Agriculture, National Institute of Food and Agriculture. https://nifa.usda.gov/adoption-precision-agriculture Accessed April 19th, 2018.
[2] Todd Janzen. "What Makes Ag Data 'Ownership' Unique," *Janzen Ag Law Blog*. January 15, 2016. http://www.aglaw.us/janzenaglaw/2016/1/15/what-makes-ag-data-ownership-unique Accessed May 15th, 2018.
[3] *Do mLabs Still Make a Difference? A Second Assessment*. July 2017. The World Bank Group, Washington, DC.
[4] "AgFunder AgriFood Tech: Investing Report," AgFunder 2017. https://research.agfunder.com/2017/AgFunder-Agrifood-Tech-Investing-Report-2017.pdf Accessed May 15th 2018.

adoption, to effecting large-scale transformation. In 2017, CGIAR launched the Inspire Challenge to begin to address this need.

Targeting of Inspire Challenge Submissions

The CGIAR Inspire Challenge seeks to leverage the global footprint, deep domain expertise, and array of public, private, and non-profit CGIAR partners as a unique mechanism for identifying new digital innovations and accelerating them on their path towards making measurable, positive change in developing economies. CGIAR has 12 cross-cutting CGIAR Research Programs (CRPs),[5] research efforts involving multiple CGIAR centers, which provided critical input in identifying the opportunities for digital innovation in agriculture.



More than 30 suggestions from the CRPs were distilled into four challenge categories:

***Disrupting impact assessment*:** apply new tools to unchain impact assessment for agriculture research for development;
Monitoring pests and diseases: create innovative disease diagnostic tools to alert to crop, livestock and fish threats;
Revealing food systems: map and monitor food system flows to inform policymakers and problem-solvers; and
Empowering data-driven farming: bring together data streams to have a positive impact on agronomic decision-making.[6]

[5] There are 12 CRPs: Policies Institutions and Markets; Agriculture for Nutrition and Health; Climate Change, Agriculture, and Food Security; Water, Land and Ecosystems; Wheat; Roots, Tubers, and Bananas; Rice; Maize; Forests, Trees, and Agroforestry; Fish; Livestock; and Grain, Legumes and Dryland Cereals.
[6] "The Inspire Challenge 2017," The Platform for Big Data in Agriculture, International Center for Tropical Agriculture http://bigdata.cgiar.org/*Inspire*/ Accessed May 12, 2018.

The process captured the input of roughly 320 agriculture development experts from an array of disciplines worldwide that may help us better understand challenges and opportunities for digital innovation in food and farming systems. A total of 120 applications from around the world were coded in order to learn more about applicants' views on the context and purpose of digital innovation in food systems, as they relate to:

- Suitable environments for digital innovation in agriculture;
- Partnerships for innovation;
- Users and beneficiaries of innovations; and
- Entry points in food and farming systems that are ready for digital innovation.

In addition, submissions were coded by the degree of *problem definition* and the *domain knowledge* level required to generate new solutions to a given problem, and categorized according to an influential framework for innovation strategy.[7] Four broad types of innovation were observed:

- Breakthrough Innovation;
- Incremental Innovation;
- Disruptive Innovation; and
- Basic Research.

Fifty-four percent of the proposals fell into the Basic Research Innovation category, while 25% of the submissions were Breakthrough Innovation, 17% were Sustaining Innovation, and 4% were Disruptive Innovation submissions. This classification suggests that fully 71 percent of the submitted proposals may not have been fully responsive to the Challenge solicitation, which asked applicants to source "big ideas" that can deliver "actionable information to farmers and inspire others to use big data to create impact." Those participants with more precisely specified problems were more likely to become finalists and winners than those with less well-defined problems. This suggests that subsequent editions of the Inspire Challenge should fine-tune the solicitation and selection process for the types of digital innovation sought .

[7] Greg Satell. "The 4 Types of Innovation and the Problems They Solve," *Harvard Business Review*, June 21, 2017. https://hbr.org/2017/06/the-4-types-of-innovation-and-the-problems-they-solve Accessed January 10th, 2018.

Inspire Challenge Success by Innovation Type			
Problem Specification	**Domain Specification**		**Competition Stage**
	Not Well	Well	
Well	**Breakthrough innovation**	**Sustaining innovation**	
	25%	17%	Submissions
	25%	42%	Finalists
	40%	60%	Winners
Not Well	**Basic research innovation**	**Disruptive innovation**	
	54%	4%	Submissions
	33%	0%	Finalists
	0%	0%	Winners

The Inspire Challenge and Digital Innovation Strategies for Agriculture

Based on our review of the CGIAR Inspire Challenge, there may be some new approaches for fostering innovation that merit further trial and investigation. One key finding is that all types of innovation have a role in digital agriculture development. The design of the 2017 Inspire Challenge was more suited to some types of innovation than others; however, innovation works best when approaches are well-matched to the types of problems they seek to solve. Among the various approaches, each can play a role in helping big data work more effectively and efficiently across the agricultural sector.

CGIAR is uniquely positioned to leverage an array of digital innovation approaches, from local to global scales, through widening the numbers and types of digital agriculture partners and through partnering for different purposes: collaboration on problems with reasonably well-defined solutions, sourcing new knowledge for reasonably well-defined problems, or sourcing new types of problems that can be addressed through collaboration or open innovation.

As the sector continues to investigate innovation strategies for digital agriculture, each type of innovation may merit its own focus and special mix of collaboration, competition, and partnerships for building resilient food systems worldwide.

Why a Challenge?

Global agriculture is increasingly driven by data. Advances in computing power, data storage, and data communications over the last 30 years have given rise to powerful tools for helping make farming and food systems more precise, profitable, and adaptive. Newer digital innovations -- including machine learning, the expansion of connected sensor technologies, and robotics -- promise more dramatic changes in the farming landscape in the near future.

This transformation is happening in both developed and developing economies. In industrialized agriculture, precision farming has demonstrated how technologies such as variable rate application, computer-guided mechanization, and telemetric irrigation can help farmers manage production at very specific times and locations, and these technologies are increasingly integrated with analytic tools to help support farming decisions in real time.[8] In developing agriculture sectors, expanding data access and nearly ubiquitous access to telephony[9, 10] has accelerated economic activity overall and in the sector in particular.[11] These services are enabling a wave of new digital agriculture startup activity.[12]

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[8] Perrett, E., Heath R. , Laurie, A. & Darragh, L. *Accelerating precision agriculture to decision agriculture – analysis of the economic benefit and strategies for delivery of digital agriculture in Australia*, Australian Farm Institute and Cotton Research and Development Corporation, Sydney, November 2017. Available online <https://www.crdc.com.au/sites/default/files/P2D%20Ecomomic%20impact%20of%20digital%20ag%20-%20AFI%20Final%20Report.pdf>

[9] In 2016 teledensity (number of phones by population) exceeded 100% in most geographic regions and was at least 74% in the lowest region, though significant gaps remain in rural telephony coverage (International Telecommunications Union, *World Telecommunication/ICT Development Report and Database, 2018*).

[10] According to the International Telecommunications Union,   in 2018 "[m]obile broadband is more affordable than fixed-broadband services in most developing countries." (*ICT Facts and Figures 2017*, ITU, 2018, p. 5.)

[11] For examples, see: Jenny C. Aker and Isaac M. Mbiti. "Mobile Phones and Economic Development in Africa," *Journal of Economic Perspectives*, vol. 24, no. 3, Summer 2010, pp. 207-32. Megumi Muto and Takashi Yamano.   "The Impact of Mobile Phone Coverage Expansion on Market Participation: Panel Data Evidence from Uganda," *World Development*, vol. 3, no. 12, 2009, pp. 1887-1896. Robert Jensen; The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector, *The Quarterly Journal of Economics*, Volume 122, Issue 3, 1 August 2007, Pages 879–924, https://doi.org/10.1162/qjec.122.3.879

[12] Lina Belmaachi, "African Agtech Market Map: 99 Technologies Changing the Future of Agriculture in Africa," AgFunder News, February 14, 2018. https://agfundernews.com/african-agtech-market-map.html, Accessed May 20, 2018.

However, digital agriculture worldwide has not realized its full potential. Despite very active promotion from industry, to date, the real rates of adoption of precision agriculture have been slow in most industrialized economies, where market offerings tend to favor large farms or high-value specialty crops.[13] Farmers, and those who serve them, must navigate an array of competing standards for equipment and services,[14] geospatial information,[15] sensors,[16] and communications protocols,[17] contributing to legitimate fears of vendor lock-in.[18] Farm data ownership and, as a result, the best way forward for the free flow of data, remains unclear.[19]

In developing economies, digital agriculture technologies have found even less of a foothold. Recent World Bank research in Kenya, Senegal, South Africa, and Armenia found that telecommunications companies, value-added service providers, application developers, and other actors in the mobile application ecosystems of these countries perceived the agricultural sector to be the least impacted by digital technology and well behind other economic sectors[20] and only five of the 73 digital technology firms surveyed identified the agricultural sector as a source of potential revenue. Similarly, the Indian Institute for Economic Growth found great potential for innovative digital disruptions in food value chains, as well as indications of improved livelihoods among connected small farmers, but also noted that the financial ecosystem for supporting these innovations is incomplete and potential investors continue to perceive digital agriculture as an overly risky investment.[21] AgFunder's 2017 *AgriFood Tech Investment Report* notes the overall rate of seed funding for startups has slowed, despite the existence of numerous technology accelerators and incubators worldwide. This does not bode well for the future of digital innovation in this sector.[22]

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13 "Adoption of Precision Agriculture," United States Department of Agriculture, National Institute of Food and Agriculture. https://nifa.usda.gov/adoption-precision-agriculture Accessed April 19th, 2018.
14 European Commission. Smart Farming Group Key Messages. https://ec.europa.eu/futurium/en/system/files/ged/report_smart_farming.pdf. Accessed April 30th, 2018.
15 "OGC announces a new standard that improves the way information is referenced to the earth," Open Geospatial Consortium Press Release, Tuesday, 24 October 2017 < http://www.opengeospatial.org/pressroom/pressreleases/2656> Accessed May 15th, 2018.
16 Srđan Krčo and Boris Pokrić. "From Precision Agriculture to Prescription Agriculture," IEEE Internet of Things Newsletter, November 8, 2016. https://iot.ieee.org/newsletter/november-2016/from-precision-agriculture-to-prescription-agriculture.html Accessed May 15th, 2018.
17 Kais Mekki, Eddy Bajic, Frederic Chaxel, Fernand Meyer, "A comparative study of LPWAN technologies for large-scale IoT deployment," ICT Express, 2018, ISSN 2405-9595, https://doi.org/10.1016/j.icte.2017.12.005 Accessed May 15th, 2018.
18 Sjaak Wolfert, Lan Gea, Cor Verdouwa, and Marc-Jeroen Bogaardt. "Big Data in Smart Farming – A review" *Agricultural Systems,* v. 153, May 2017, pp. 69-80.
19 Todd Janzen. "What Makes Ag Data 'Ownership' Unique," *Janzen Ag Law Blog*. January 15, 2016. http://www.aglaw.us/janzenaglaw/2016/1/15/what-makes-ag-data-ownership-unique Accessed May 15th, 2018
20 *Do mLabs Still Make a Difference? A Second Assessment*. July 2017. The World Bank Group, Washington, DC
21 N. Chandrasekhara Rao, Rajib Sutradhar, and Thomas Reardon. Small farmers and disruptive innovations in food value chains in India, Policy Brief, Institute of Economic Growth. Sept. 2017. http://www.iegindia.org/upload/publication/280617_191616PB%209%202017.pdf Accessed May 15th, 2018.
22 "AgFunder AgriFood Tech: Investing Report," AgFunder 2017. https://research.agfunder.com/2017/AgFunder-Agrifood-Tech-Investing-Report-2017.pdf Accessed May 15th 2018.

Innovation in emerging economies may still prove to be the catalyst that moves global digital agriculture forward. We have seen something similar begin to happen in the financial sector. In countries where mobile money is well-diffused and adopted, innovations in financial services delivery are reaching even very rural, low-income customers[23] and creating pathways to greater wealth.[24] Many governments and the financial industry have taken note and have taken steps to reduce the cost and friction of the free flow of value, helping expand services to the underserved.[25] Agriculture can be next.

Accelerators, incubators, hackathons, data jams, corporate labs, public research institutions—there is no lack of processes and places created to foster digital innovation in developing economies, and, yet, rarely do these digital innovations find a foothold and a path to scale in the agriculture sector. We have much to learn about how to better target these efforts. What is, for example, a suitable environment for digital innovation in agriculture? What challenges are digital innovations best suited to address, and what are the high-potential entry points in value chains, market systems, and food systems overall? What system-level interventions might drive down the costs or increase the success rate of these digital innovations?

[23] "Kilimo Booster: Musoni Launches an Agricultural Loan for Kenya's Smallholder Farmers," Grameen Foundation, March 2015. https://grameenfoundation.org/resource/kilimo-booster-musoni-launches-agricultural-loan-kenya%E2%80%99s-smallholder-farmers Accessed May 16th, 2018.

[24] Households with access to mobile money in Kenya were demonstrated to be 100% protected from consumption during economic shocks. See Jack, William, and Suri, Tavneet, "Risk Sharing and Transactions Costs: Evidence from Kenya's Mobile Money Revolution," *American Economic Review*, 104 (1), 2014, pp. 183-223.

[25] "Unified Payments Interface (UPI)," Ministry of Electronics & Information Technology, Government of India. http://cashlessindia.gov.in/upi.html Accessed May 18th.

The CGIAR Inspire Challenge

CGIAR, a global consortium of agriculture development research institutes, launched the Inspire Challenge as an open innovation process to reveal and act on opportunities for digital agriculture innovation. The CGIAR Inspire Challenge seeks to leverage the global footprint, deep domain expertise, and array of public, private, and non-profit CGIAR partners as a unique mechanism for identifying new digital innovations and accelerating them on their path towards making measurable, positive change in developing economies.

Locations of agricultural development research conducted by CGIAR 2010-2016.[26]
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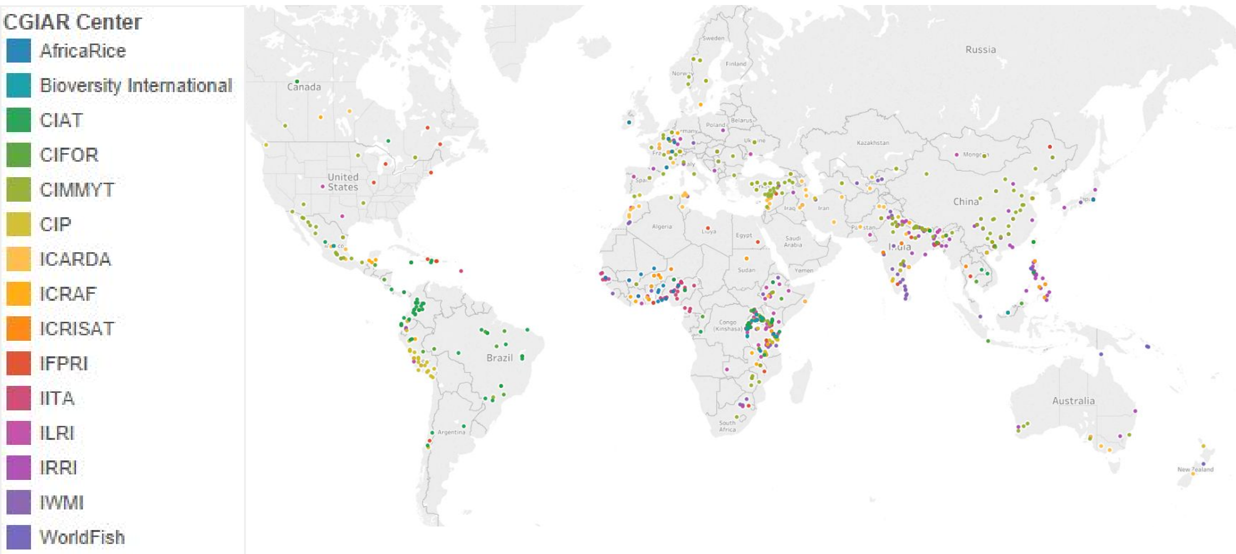

[26] HarvestChoice, International Food Policy Research Institute; International Center for Tropical Agriculture, 2017, "CGIAR Scientometrics Data for 2000-2016," https://doi.org/10.7910/DVN/ZV1JCQ, Harvard Dataverse, V3 Accessed May 18th.
[27] There are 12 CRPs: Policies Institutions and Markets; Agriculture for Nutrition and Health; Climate Change, Agriculture, and Food Security; Water, Land and Ecosystems; Wheat; Roots, Tubers, and Bananas; Rice; Maize; Forests, Trees, and Agroforestry; Fish; Livestock; and Grain, Legumes and Dryland Cereals.

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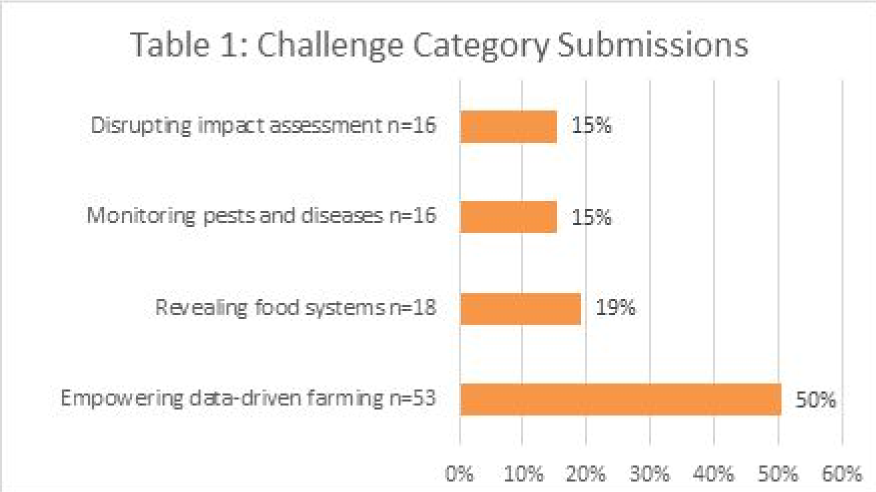


Teams of CGIAR researchers paired with non-CGIAR partner organizations of any type were invited to propose 12-month, $100,000 projects. The Challenge drew 120 submissions from 37 countries, with roughly 320 team members participating. Half of the responsive proposal submissions were in the Data-Driven farming category, with the remaining submissions spread fairly evenly across the other categories (see Table 1).[29] Twelve of the 15 CGIAR consortium centers participated in the Challenge.

For a proposal to be fully responsive, it needed to leverage the distinct capabilities of CGIAR researchers and non-CGIAR partners to create something new. The Big Data Platform management team assessed these two criteria -- "collaboration" and "newness" -- to rank the responsiveness of the submissions and select 12 finalists. The finalists' proposals were sent to a judging panel for full evaluation.

The seven-member judging panel included two CGIAR representatives and five external experts, representing funders (e.g. foundations, public grant-making institutions), public and private sectors, and academia. Judges were provided with the

[28] "The Inspire Challenge 2017," The Platform for Big Data in Agriculture, International Center for Tropical Agriculture http://bigdata.cgiar.org/Inspire/ Accessed May 12, 2018.
[29] Due to insufficient detail, only 103 of the 120 total submissions were codeable by submission category.

12 finalist proposals, a document summarizing a review of each submission by a gender expert, and a scorecard with the following criteria:

- Scope and relevance
- Use of information/data
- Design and implementation
- Pitch and demo
- Maintenance and sustainability

Judges and finalists all attended the September 2017 CGIAR Convention on Big Data in Agriculture for the final Challenge phase. Challenge teams had three defined opportunities at the Convention in which to make their case: two minutes in the first day's plenary session to introduce themselves and their projects; an open, 90-minute "bazaar" on the second day, during which applicants staffed stalls or tables where all Convention attendees could come learn more about their proposals; and a final, seven-minute pitch to Challenge judges in a plenary session on the third day. Five grant awardees were selected, which were announced the final evening of the Convention.

The Challenge and Innovation Strategies for Digital Agriculture

The 2017 CGIAR Inspire Challenge sought to leverage the global footprint, deep domain expertise, and array of public, private, and non-profit partners of CGIAR as a unique mechanism to identify opportunities for digital agriculture innovation, and to begin to develop new learning about how to better target innovation strategies. The process captured the input of roughly 320 agriculture development experts from an array of disciplines worldwide that may help to better understand challenges and opportunities for digital agriculture innovation, addressing such questions as:

- Where are the suitable environments for digital innovation in agriculture?
- Who are the best innovation partners?
- Who will benefit from the innovation?
- What are high-potential entry points in food systems?
- What data is important for food system innovation?
- How best to match types of innovation with the problems they seek to address?

Gaining insight into these questions is a first step towards better equipping CGIAR and its partners to leverage digital innovations and chart a clearer course to effecting positive change in developing economies.

Where are the suitable environments for digital innovation in agriculture?

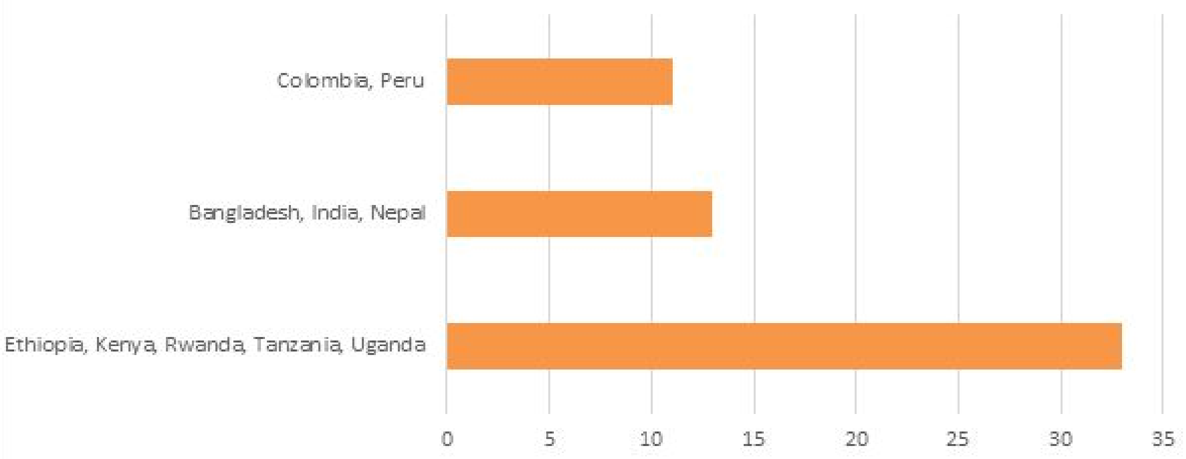
Table 2: Proposed Pilot Location

Data availability and connectivity as well as a diverse and growing digital economy would seem to be necessary pre-conditions for digital innovations to find a foothold. Does this assumption align with the thinking and submissions of this global group of innovators?

Applicants targeted a total of 31 countries worldwide in their proposals. Seven of them identified whole regions (South Asia and Africa) and 26 were unclear about where their pilot might be conducted (see Table 2). Three regional clusters are noted: Ethiopia, Kenya, Rwanda, Tanzania, and Uganda led with 33 proposals identifying these areas as preferred pilot sites (see Table 2); followed by Bangladesh, India, and Nepal with 13; and Colombia and Peru with 11 (see Table 3).

Countries and regions with CGIAR Research Centers were preferred pilot sites for innovation, but it also appears that most of the pilot locations explicitly mentioned in proposals have an enabling mix of policy, economic conditions, public or private champions, digital expertise and services, innovation centers, and receptivity of potential beneficiaries to adopting innovations. Countries in the Common Market for East and Southern Africa (COMESA), for example, were the target site for more than 50 proposed pilot projects. COMESA has long supported the free flow of physical and digital commerce in the region.[30] Digital innovation hubs may also be a feature of the enabling environment. A recent World Bank assessment found that the East Africa Mobile Innovation Lab (mLab) was, among many other mLabs worldwide, the most focused on the agricultural sector.[31] Active public participation in spurring the digital economy is a feature of most of the high-target countries, and this is a critical enabler of digital innovation.[32] A 2017 study by Tufts University found that the environment in a majority of the high-target countries enabled "rapidly advancing" digital economies.[33]

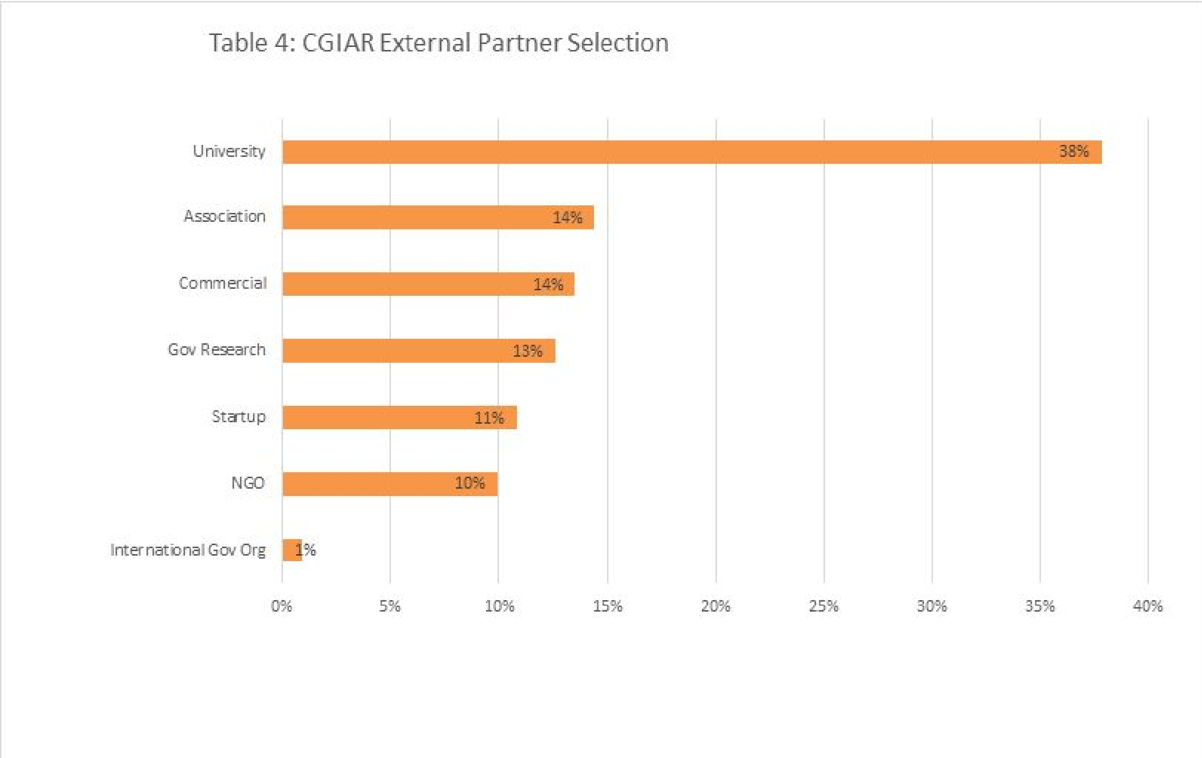
Table 3: Proposed Pilot Location Clusters



[30] In a boost to digital agriculture, COMESA recently invested in a digitized seed catalog spanning the member states: https://varietycatalogue.comesa.int/web/
[31] *Do mLabs Still Make a Difference? A Second Assessment*. July 2017. The World Bank Group, Washington, DC.
[32] Ibid.. p. 29.
[33] Chakravorti, B. & Chaturvedi, R., *Digital Planet 2017: How Competitiveness and Trust in Digital Economies Vary Across the World*. Tufts University. July 2017, https://sites.tufts.edu/digitalplanet/files/2017/05/Digital_Planet_2017_FINAL.pdf

Who are the best innovation partners?

The Inspire Challenge was designed to source and integrate a diversity of views both internal and external to CGIAR and apply them to agriculture development challenges. The diversity and type of views brought to bear on these challenges is directly related to the types of new partnerships forged. The types of partners most commonly allied with the CGIAR proponents are summarized in Table 4.

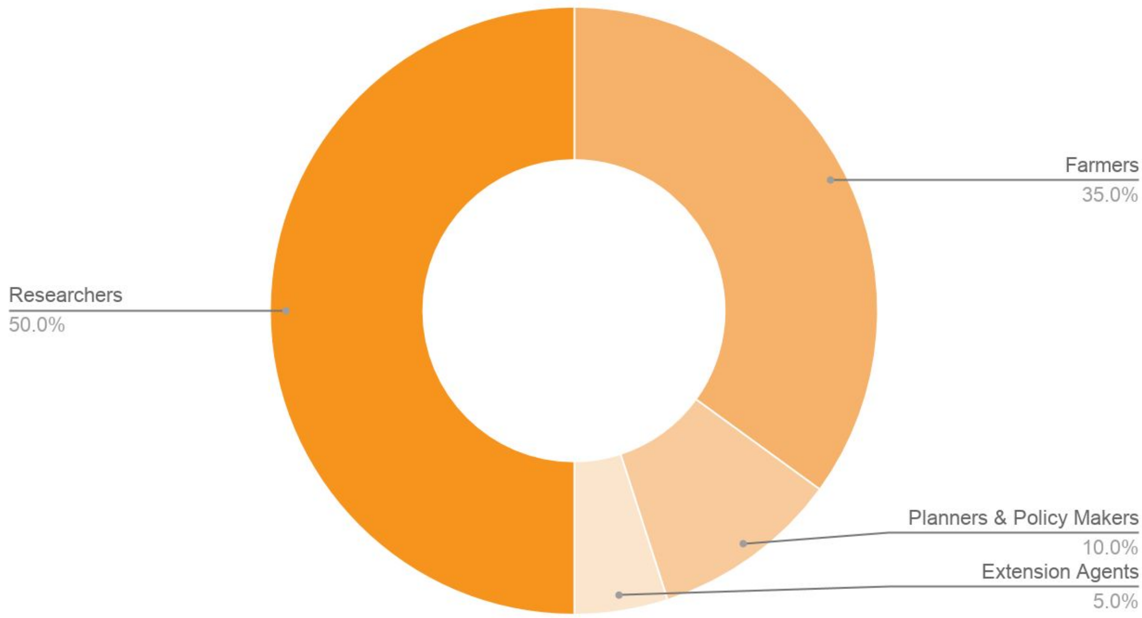


The leading partners are universities and public research organizations. This is not surprising, considering that the CGIAR centers and these institutions share a similar, public-good mission. It may also indicate that more diverse views are needed in CGIAR's digital innovation efforts and that the Challenge may need to encourage more new types of partnerships in order to create new pathways to solving agricultural problems.

Who will benefit from the innovation?

If digital innovations are to effect positive changes in agricultural development, we should have a clear idea of who needs to benefit. Half of the targeted direct beneficiaries of the Inspire Challenge were researchers, followed by farmers, policy makers, and extension agents (see Figure 1). While it may not be surprising that digital innovations for research are targeted by a large portion of the applicants, this implies that the path to impact among farmers, extension agents, and policy makers is not as direct as was desired. The Challenge sought to source ideas that would enhance impacts on farmer wellbeing in a much nearer term than, say, crop improvement programs typically do.[34]Finding such paths to positive change might be facilitated by increasing the specificity of the problem that a proposed innovation will address or else by seeking more diverse partnerships.[35]

Figure 1: Applicants' Target Beneficiaries



[34] For example, the International Center for Tropical Agriculture began cassava research in 1967, yet "its impact was first felt only in the 1980s." Prabhu L. Pingali "Green Revolution: Impacts, limits, and the path ahead." *Proceedings of the National Academy of Sciences of the United States of America*. U.S. National Academy of Sciences. July 31, 2012, vol. 109, no. 31, pp. 12302-12308 https://doi.org/10.1073/pnas.0912953109 Accessed February 3rd, 2018.

[35] Existing CGIAR pre-competitive alliances with multinational life sciences companies may provide one model. These firms are now the leading source of innovation in agricultural science and research collaborations with them have a built-in path to scale. See: Prabhu L. Pingali "Green Revolution: Impacts, limits, and the path ahead." *Proceedings of the National Academy of Sciences of the United States of America*. U.S. National Academy of Sciences. July 31, 2012, vol. 109, no. 31, pp. 12302-12308 https://doi.org/10.1073/pnas.0912953109 Accessed February 3rd

What are the high-potential entry points in food systems?

The Inspire Challenge submissions enable us to examine the aggregate view from roughly 320 food security experts on entry points in food systems that are ready for digital innovation. To do this, proposals were coded according to their target entry points in the system.[36] Many applicants targeted more than one entry point; to manage this, the number of entry points targeted by any single applicant was normalized to 1.[37] Submissions were further grouped into four more broad categories for ease of comparison: *Pre-Production*, *On-Farm*, *Post-Harvest*, *Consumption and Nutrition*, and *Unspecified Food System*[38] (see Table 5).

Table 5: Food System Categories				
Pre-Production	Planning		Inputs	
On Farm Production	Planting		Growing	Harvesting
Post Harvest	Storage	Processing	Transport	Access to Markets
Consumption & Nutrition	Consumption		Nutrition	
Unspecified Food System				

Entry points in "On Farm Production" were the most targeted by applicants (47% of the total number of proposals submitted), whereas "Consumption & Nutrition" was the least targeted. These results are consistent when examined in disaggregated form by submission category (see Table 6). "Unspecified Food System" entry points are largely seen as equally or more important than Pre-Production and Post-Harvest entry points;

[36] The coding was inclusive: if an applicant targeted "crop yield" it was mapped to the pre-production and the on-farm production food system areas. Fifteen applicants who were unclear about what impact they might have on the food system and the seven that did not indicate a submission category were excluded from this analysis.
[37] To normalize applicants' entry points the average value of each point was calculated. For example, if a proposal identified three food system areas then each area is assigned a value of 1/3; if five food system areas were identified, then each was assigned a value of 1/5, and so on. As a result, each applicant has a normalized entry point total of 1.
[38] Targets not linked to a discernible part of the food system (e.g. integrating unspecified data sets, or increasing Wi-Fi access) were labeled as *Unspecified Food System*.

in many cases these proposals sought to improve or reveal something about the overall system (i.e. in response to the "Revealing Food Systems" category) through new application of data or digital technologies.

Table 6: Food System Impact Target by Innovation Focus					
Innovation Focus	**Pre-Production**	**On- Farm Production**	**Post-Harvest**	**Consumption & Nutrition**	**Unspecified Food System**
All Submissions	**17%**	**47%**	**10%**	**1%**	**25%**
Monitoring Pests/-Disease	8%	61%	11%	0%	20%
Disruptive Impact Assessment	15%	40%	0%	0%	45%
Revealing Food-System	23%	32%	21%	0%	23%
Empowering Data-Driven Farming	19%	48%	8%	3%	22%

What data is important for food system innovation?

Applicants identified an array of data sources that are relevant to food systems research. Coding data sources by their intersection with the food system yields results that are consistent with the targeting of food system innovations (see Table 7).

Table 7: Food System Area Data Sources by Innovation Focus

Innovation Focus	Pre-Production	On- Farm Production	Post-Harvest	Consumption & Nutrition	Unspecified Food System
All Submissions	**14%**	**35%**	**8%**	**1%**	**41%**
Monitoring Pest-/Disease	20%	49%	1%	0%	30%
Disruptive Impact Assessment	8%	20%	4%	0%	68%
Revealing Food-System	8%	29%	17%	0%	46%
Empowering Data-Driven Farming	16%	36%	9%	3%	36%

This may give us some insight into the utility of and demand for different data sources and types in the sector. A number of CGIAR-generated datasets are intended to be used. In addition, other, non-research data sources that are not explicitly related to the food system are noted as being of significant relevance to digital innovation across all categories. These data sources include publicly-generated satellite imagery or climate data (such as those images and data generated by NASA and/or ESA), social media, or metadata generated by mobile phone networks. This suggests that investment in datasets with very broad utility can yield specific impacts in food systems, and that the sector could develop more wide-ranging or novel alliances to develop such assets for the broader data ecosystem. Specific data sources identified by applicants are listed in Table 8.

Table 8: Specific Data Sources Identified

1. The Projecting Responses of Ecological Diversity In Changing Terrestrial Systems (PREDICTS) database
2. CGIAR- generated agricultural climate risk data
3. CGIAR soil and cultivar data
4. National Oceanic and Atmospheric Administration (NOAA) weather/climate data
5. UN Comtrade (trade data)
6. Food and Agriculture Organization (FAO) statistics on food production and basic use.
7. World Health Organization health and nutrition information
8. UNHabitat (Global Urban Indicators database)
9. Twitter
10. LANDSAT and SENTINEL satellite imagery
11. FAO soil grids data
12. Soil Moisture Active Passive (SMAP) from the National Aeronautics and Space Administration (NASA)
13. National Agricultural Census; National Agricultural Survey; and National Bureaus of Statistics
14. Living Standards Measurement Study (LSMS) database
15. CGIAR sustainable land management database (using Land Degradation Neutrality indicators)
16. CGIAR DNA fingerprinting data
17. Mobile Network Operator Call Record Data
18. A global agribusiness firm's Farmer Information System database
19. Demographic and Health Surveys (DHS)
20. European Space Agency land cover maps
21. Global gridded human population data from the Socioeconomic Data and Applications Center (SEDAC)
22. International Food Policy Research Institute (IFPRI)/Harvest Choice Market Distance Dataset
23. World Database of Protected Areas
24. IFPRI Global Hunger Index
25. The Hunger and Nutrition Commitment Index (HANCI)
26. Economist Food Systems Indicator
27. YieldGap.org
28. OpenAgFunding initiative
29. International Soil Reference and Information Center (ISRIC) SoilGrids (Organic Matter non-response soils)
30. CGIAR data from historical potato landrace registers
31. CGIAR Genebank data
32. CGIAR open data repositories
33. Normalized Difference Vegetation Index (NDVI) data generated from public imagery
34. HarvestChoice spatially-explicit; bio-physical and economic data
35. IFPRI Spatial Production Allocation Model (SPAM) cropping system data, spatial distribution of crops
36. Open source satellite and weather data
37. IBM weather forecast

How best to match types of innovation with the problems they seek to address?

In addition to providing some useful data to examine the context and purpose of digital innovation in food systems, the Challenge can be examined through the lens of a more general innovation strategy. According to one influential framework,[39] for example,

[39] Greg Satell. "The 4 Types of Innovation and the Problems They Solve," Harvard Business Review, June 21, 2017. https://hbr.org/2017/06/the-4-types-of-innovation-and-the-problems-they-solve Accessed January 10th, 2018.

innovations can categorized by the degree of *problem definition* and the *domain knowledge* level required to generate new solutions to a given problem. This categorization suggests four broad types of innovation:

- Breakthrough Innovation;
- Incremental Innovation;
- Disruptive Innovation; and
- Basic Research.

Each of type of innovation has its own common timeframe for coming to fruition, with varying degrees of predictability. More defining characteristics of each type of innovation are outlined in Table 9.

<table>
<tr><th colspan="3">Table 9: Innovation Type</th></tr>
<tr><th rowspan="3">Problem Definition</th><th colspan="2">Domain Definition</th></tr>
<tr><th>Not Well</th><th>Well</th></tr>
<tr><th>Breakthrough Innovation</th><th>Sustaining Innovation</th></tr>
<tr><td>Well</td><td>Problem is well defined but knowledge on how to solve it not well understood.
Objective is to discover what knowledge is needed to solve a set of known problems.
e.g. Lockheed U-2 Dragon Lady aircraft.
Location: Contests, challenges and prizes; project lab.
Time to Success: Unpredictable.</td><td>Problem is clearly defined and there is a well-defined understanding of how to solve it.
Objective is to improve on an existing product.
e.g. 1,000 songs on an iPod.
Location: R&D lab; collaborative community.
Time to Success: 2-3 years; predictable.</td></tr>
<tr><td rowspan="2">Not Well</td><th>Basic Research</th><th>Disruptive innovation</th></tr>
<tr><td>Problem is not clearly defined and there is poorly defined knowledge on how to solve it.
Objective is to create knowledge that can be used in future research or further down the product development life-cycle.
e.g. Development of the CRISPR gene- editing tool; Haber's development of the ammonia-synthesis process.
Location: Research institutions: PARC, Bell Labs, universities.
Time to Success: 10 years or more; unpredictable results.</td><td>Problem is not as clearly defined, but the potential knowledge that might be used is a known quantity.
Objective is to deploy a new approach/business model to an underperforming, existing solution and change/create a market.
e.g. Twiga Foods: short circuits the supply chain between small-scale retailers and farmers; Android mobile OS (free).
Location: VC-funded enterprises; startups; incubators and accelerators; internal development labs.
Time to Success: 2-3 years; many failures.</td></tr>
</table>

To assess the innovation type of each Inspire Challenge proposal, these were coded according to how well applicants *specified the problem* they sought to address or the solution they proposed, and how well they *defined the knowledge* required to solve the problem or implement the solution.[40] This exercise suggests that 54% of the proposals fell into the Basic Research Innovation category, while 25% of the submissions were Breakthrough Innovation, 17% were Sustaining Innovation, and 4% were Disruptive Innovation submissions. This classification suggests that fully 71 percent of the submitted proposals -- 54 percent in the Basic Research Innovation category and 17 percent in Sustaining Innovation -- may not have been fully responsive to the Challenge solicitation, which asked applicants to source "big ideas" that can deliver "actionable information to farmers and inspire others to use big data to create impact." [41]

According to Satell,[42] Basic Research typically takes a decade or more to yield results, whereas Sustaining Innovation is not suited to sourcing new "big ideas." Open innovation processes such as the Inspire Challenge perform best when new approaches are desired, and either the knowledge base or the problem is not well-defined.[43] This is consistent with the success rates among participants in the 2017 Inspire Challenge: submissions with more precisely specified problems were more likely to become finalists and winners than those with less well-defined problems (see Tables 10 and 11).

Table 10: Distribution of Inspire Challenge Applicants by Innovation Type

Problem Specification	Domain Specification	
	Not Well	Well
Well	**Breakthrough innovation** 25%	**Sustaining innovation** 17%
Not Well	**Basic Research Innovation** 54%	**Disruptive innovation** 4%

[40] Applicants' own claims were taken at face value. Proposals that were specific about the problem definition or domain expertise to address it were coded "high" on those axes, and those that were vague were coded as "low."
[41] *Inspire Challenges* Announcement, http://bigdata.cgiar.org/inspire/ Accessed August 4, 2017.
[42] Greg Satell. "The 4 Types of Innovation and the Problems They Solve," *Harvard Business Review*, June 21, 2017. https://hbr.org/2017/06/the-4-types-of-innovation-and-the-problems-they-solve Accessed January 10th, 2018.
[43] Ibid.

Table 11: Inspire Challenge Success by Innovation Type

Problem Specification	Domain Specification: Not Well	Domain Specification: Well	Competition Stage
Well	**Breakthrough innovation**	**Sustaining innovation**	
	25%	17%	Submissions
	25%	42%	Finalists
	40%	60%	Winners
Not Well	**Basic research innovation**	**Disruptive innovation**	
	54%	4%	Submissions
	33%	0%	Finalists
	0%	0%	Winners

Conclusions: Innovation Strategies for Digital Agriculture

Determining what innovation strategies and processes the sector as a whole must target or improve is a difficult proposition, and this review of the CGIAR Inspire Challenge has no pretensions of being such an ambitious undertaking. Nevertheless, some observations from this review may suggest some new approaches that merit further trial and investigation.

The sector is still building its "Big Data" capabilities and understanding its data needs.

Most of the Inspire Challenge proposals submitted were on the periphery of what are commonly considered to be "big data" projects: combining large structured data sets (***volume*** of data), large volumes of continuous real time data (***velocity*** of data), with unstructured data (***variety*** of types data).[44] A number of proposals noted the use of Internet of Things (IoT) remote devices, unmanned aerial vehicles and satellite imagery, and that machine learning or artificial intelligence would be helpful, but few articulated how they would combine this data with other existing structured or unstructured data to achieve quicker or larger-scale solutions. Building a more detailed picture of the data ecosystem needed to support researchers, participants at different links in agricultural value chains, innovators, and beneficiaries in building resilient food systems may help more successful big data projects to emerge in the agricultural sector.

All types of innovation have a role in digital agriculture development.

The 2017 Inspire Challenge was designed to develop new pathways to impact, and, as a result, was most likely suited to some types of innovation more than others. This is not to imply that all types of innovation do not have a role in digital agriculture development. Innovation works best when approaches are well-matched to the types of problems they seek to solve. Open innovation processes tend to be most successful,

[44] Andrew McAfee and Erik Brynjolfsson. "Big Data: The Management Revolution," *Harvard Business Review*, October 2012. https://hbr.org/2012/10/big-data-the-management-revolution Accessed April 15, 2018.

for example, when the problems they seek to solve are well-specified, the solutions serve a strategic or tactical objective, and the required types of knowledge to find a solution are not well-defined.[45] Collaboration tends to yield the best results in terms of innovation when "participants can accumulate and recombine ideas, sharing information freely."[46] Contests or competitive processes, for their part, tend to work well when it's not obvious what combination of skills or even technical approaches are needed.[47] Each of these approaches has a role in helping big data enable agriculture development.

There are opportunities for CGIAR to employ collaboration, competition, and a mix of these approaches around bottleneck issues for the sector. If a dearth of reliable localized climate forecasts is a fundamental problem, as was indicated by several applicants, for example, stakeholders could collaborate on developing known solutions (e.g. integrating existing climate data streams to produce good quality data assets for the sector), co-design a competitive open innovation process targeting problems in need of new knowledge to address them (e.g. new ways of sourcing or integrating meteorological data), and then collaborate again on the mainstreaming or scaling-up of successful innovations.

Projects with fungible potential benefits and broad utility should lend themselves well to this mix of collaboration and competition. For example, demonstrating scalable, cost-effective methods and technologies for integrating sensor networks across farms, fisheries, or landscapes in developing economies could facilitate food system interventions and coordination by an array of actors such as food companies, distributors, certifiers, and farmers themselves enabling new levels of "whole of system" intelligence and coordination. Such an undertaking is, by definition, multi-stakeholder: harmonization of efforts among researchers and public, private, and non-profit organizations would help drive down the costs of the innovation and build its path to adoption at scale.

CGIAR is uniquely positioned to leverage this array of innovation approaches, from local to global scales, through widening the number and types of digital agriculture partners and through partnering for different purposes: collaboration on problems with reasonably well-defined solutions,[48] sourcing new knowledge for reasonably

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[45] Kevin Boudreau and Karim Lakhani. "Using the Crowd as an Innovation Partner," Harvard Business Review, April 2013, pp. 5-16. https://hbr.org/2013/04/using-the-crowd-as-an-innovation-partner Accessed April 15th, ,2018.

[46] Ibid.

[47] Ibid. pp. 9-16.

[48] One good example of a well-defined solution: designing a robot that can insert a wire electrode into a fly with the capacity to wire 1,000 flies a day, 100 times the typical productivity of a graduate student. The greater output and lower cost can fundamentally change the scientific approach of fly research, dramatically increasing the number of analyses that can be performed, and could potentially accelerate research findings. See Savall, Joan et al. "Dexterous Robotic Manipulation of Alert Adult *Drosophila* for High-Content Experimentation." *Nature methods* 12.7 (2015): 657–660. *PMC*. https://pyramidal.stanford.edu/publications/Savall-nmeth.3410.pdf Accessed June 4th, 2018.

well-defined problems, or sourcing new types of problems that can be addressed through collaboration or open innovation.

Innovation is difficult and unpredictable

Technological innovation has been shown to be "uncoordinated, integrative, and synthetic […] rather than a deliberate effort of an epochal breakthrough."[49] Significant breakthroughs can result from iterative, little-connected efforts bridging domains and types of innovation. The Clustered Regularly Interspaced Palindromic Repeats (CRISPR) gene editing tool, for example, emerged after roughly 20 years' development with 10 different research teams making significant and attributable contributions. The tool was built first by basic research innovators who were driven by "personal curiosity (to understand bizarre repeat sequences in salt-tolerant microbes), followed by others responding to a military exigency (to defend against biological warfare), and still others seeking an improvement in an industrial application (to improve yogurt production)—none of whom set out to develop a tool to edit genomes."[50]

As the sector continues to investigate innovation strategies for digital agriculture, each type of innovation may merit its own focus and special mix of collaboration, competition, and partnerships for building resilient food systems worldwide.

[49] Richard K. Betts. *Cruise Missiles: Technology, Strategy, Politics*. Washington D.C.: Brookings, 1982. p. 3
[50] Eric S. Lander. "The Heroes of CRISPR," *Cell* 164, January 14, 2016. p. 26.