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in Agriculture

TOWARD A DIGITAL ONE CGIAR

Strategic research on digital transformation in food, land, and water systems in a climate crisis

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CGIAR, Platform for Big Data in Agriculture

The CGIAR Platform for Big Data in Agriculture is a cross-cutting program of the global CGIAR consortium. The Platform tends to data standards and data sharing, digital innovation strategy and technology transfer, and research into the intersection of digital technologies and agricultural development in emerging regions.

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ABSTRACT

The global research consortium CGIAR is restructuring itself to build a more integrated global organization that fully leverages its strengths and refocuses its research strategy through 2030 in service of a renewed mission*: End hunger—through science to transform food, land, and water systems in a climate crisis.* The CGIAR Platform for Big Data in Agriculture led strategic research in support of this effort, looking into digital trends that have the potential to transform global agriculture in the coming years, the roles public-interest organizations should play in the digital agriculture landscape, and the capabilities CGIAR must have if it is to use data and digital technology to their full potential in the service of its mission.

The team conducted 165 surveys with researchers and an array of stakeholders in the agricultural research-for-development ecosystem; 80 semi-structured interviews with experts in agribusiness, food companies, development funding and finance organizations, large information technology firms, consultancies, life sciences organizations and start-up firms; and 10 internal CGIAR focus group workshops. These were complemented with literature research.

There is unprecedented innovation at the intersection of digital technologies and life sciences that—if harnessed and applied—can provide the tools humanity needs to adapt to or mitigate some of its most pressing food security challenges. The research points to four broad intervention areas where CGIAR can play a key role in achieving this: advancing responsible data sharing, standards, and intermediation; applying artificial intelligence responsibly; partnering to expand digital services to reach the most vulnerable populations; and developing digital trust and digitally-enabled collective action. An action plan is suggested for building a more unified, digitally-enabled CGIAR that will be able to fully develop this role in the sector, noting key capabilities in digital leadership and governance, data management and use, digital skills, engagement with a wider digital ecosystem, unified information infrastructure, and digital innovation strategy and management in support of the U.N. Sustainable Development Goals.

KEY CONCEPTS

Organizational capability

Something the organization does (or should be able to do) to execute its strategy.

Organizational capability model

A granular model of the organization describing what it does (or should be able to do) to realize its objectives, providing a relatively stable map of the organization, even in the event structures and roles change.

Digital capability

The ability of an organization to leverage data and digital technologies in support of some aspect or aspects of its strategy.

Digital capability model

A description of the key digital capabilities needed to support or enhance the effectiveness of organizational capabilities and deliver on the organizational strategy.

Digital governance

The process and decision-making authorities by which data and digital technologies are chosen, developed, or eliminated by the organization.

Digital strategy

How the organization will use data and digital technologies most effectively to achieve its objectives.

Strategic research

Research designed and conducted to guide the development of a strategy in light of the capabilities of the organization and trends influencing its sector or industry.

EXECUTIVE SUMMARY

The coming years will be characterized by unprecedented rates of innovation at the intersection of digital technologies and life sciences that—if harnessed and applied—can provide the tools humanity needs to adapt to or mitigate some of its most pressing challenges. The global research consortium CGIAR is restructuring itself to build a more integrated global organization ("One CGIAR") that fully leverages its strengths and refocuses its research strategy through 2030 in service of a renewed mission:

END HUNGER—THROUGH SCIENCE TO TRANSFORM **FOOD, LAND, AND WATER SYSTEMS** IN A CLIMATE CRISIS.

In 2019 and 2020, CGIAR conducted wide-ranging consultations and internal assessments to better understand how trends in the access to and use of digital technologies may affect global food security, the roles public-interest actors should play in leveraging and shaping these trends, and the capabilities One CGIAR must have if it is to use data and digital technology to their full potential in the service of the agile, adaptive ***digital transformation in food, land, and water systems in a climate crisis*** in support of the 2030 CGIAR Research and Innovation Strategy.

BOX 1: STRATEGIC RESEARCH INFORMING THE DIGITAL ONE CGIAR

165 SURVEYS

Researchers surveyed a wide range of people across CGIAR and the wider agricultural research-for-development ecosystem on the key enablers and capabilities of digital organizations.

80 SEMI-STRUCTURED INTERVIEWS

More in-depth interviews were conducted with respondents from outside CGIAR on digital trends and the organizational capabilities needed to navigate them. This included individuals in agribusiness, food companies, development funding and finance organizations, large information technology firms, consultancies, life sciences organizations, start-ups, and farmers' groups.

10 INTERNAL WORKSHOPS ON DIGITAL TRENDS AND CAPABILITIES

Focus groups were convened to gather additional targeted feedback from cross-cutting technical (e.g., crop modeling) or functional (e.g., communications) disciplines across CGIAR-identified priority initiatives, investments, and the organizational capabilities needed to fully leverage digital technologies.

LITERATURE REVIEW

Interviews and workshop findings were complemented with a review of sector development strategies, research publications, and futures analyses to identify key digital trends affecting agricultural research for development and the key areas in which public-interest actors such as CGIAR can help shape and leverage these trends to contribute to global food-security goals.

CGIAR is uniquely placed to help mitigate the risks of using digital technologies and to help guide trends in digital agriculture toward effecting positive change in agricultural research for development. There is no other research organization with the deep subject-matter expertise in virtually all aspects of food-security research, trusted partner networks, the infrastructure, and a presence on the ground in more than 100 countries needed to efficiently work across the spectrum of scientific discovery through to integrated research delivery and engagement with millions of small producers and food-system actors. CGIAR has a strong track record in leading inter-disciplinary research that combines biophysical and social sciences to combat poverty, hunger, and environmental degradation that will be essential in addressing some of the most complex, potentially devastating problems facing humankind. The CGIAR 2030 Research and Innovation Strategy and the restructuring of CGIAR into a more integrated global organization—One CGIAR—present an opportunity for the organization to develop its global capabilities and harness these digital trends to guide global food, land, and water systems toward more favorable futures by 2030.

DIGITAL TRENDS AND GLOBAL FOOD SECURITY

The CGIAR analysis (see Box 1) points to key digital trends that will likely transform global agriculture and food security in the next decade:

- There is an increasing ***unmet demand for data*** by public, private, and non-profit food-system actors due to ***restricted access, slow adoption of data standards, and digital agriculture sector fragmentation.***

- There is a growing consensus among economists and researchers that ***artificial intelligence (AI) may be the next general-purpose technology,*** building on all previous digital technologies, and is poised to affect all aspects of the economy and society; and ***AI is advancing more quickly than are the ethical or regulatory frameworks*** guiding its responsible use.

- Rapidly expanding global access to telephony and the Internet is opening new opportunities for creating ***digital agriculture services reaching even the most vulnerable populations.*** However, global ***access to these services is expanding unequally.*** As a consequence, making services for low-income small-scale producers commercially sustainable is a challenge and, as a result, members or representatives of ***rural or low-income populations are rarely engaged in the co-design of human-centered digital solutions*** to serve their needs.

- There is ***a global crisis of trust*** in institutions' use of data and digital technologies and an increasing ***demand for data-driven transparency, accountability, sustainability, and resilience*** across global value chains and food systems.

STRATEGIC INTERVENTION AREAS LEVERAGING THESE EMERGING DIGITAL TRENDS

One CGIAR presents an opportunity for CGIAR to claim an active, global leadership role in digital agriculture, shaping the trajectory of key trends transforming the sector. Specifically, One CGIAR must harness four digital trends that stand to transform global food security in the coming years:

DATA	ARTIFICIAL INTELLIGENCE	DIGITAL SERVICES	DIGITAL TRUST AND COLLECTIVE ACTION
			
Enable open data and responsible data use and exchange	**Develop responsible AI to achieve the UN Sustainable Development Goals (SDGs)**	**Enable and validate bundled digital services for food systems**	**Build trust and enable responsible collective action**
CGIAR must build on and fully **implement its 2020 Open Access and Data Management Policy;** collaborate with funders and national agricultural research agencies on **sharing data that are open and compliant with standards to make that data findable, accessible, interoperable, and reusable (FAIR); and serve as a technical resource** for public, private, and other actors seeking to unlock precompetitive data to accelerate agricultural research and development.	CGIAR must **harness its AI research capabilities and accelerate the use of AI for global food security,** building **partnerships spanning food security and computer science disciplines** to apply these tools to their fullest potential in service of the SDGs. CGIAR must continually **monitor the evolution of AI for emerging risks and opportunities, help build frameworks for ethical use and governance, and invest in the human-driven innovation** needed to leverage AI for global food security.	CGIAR must conduct **transdisciplinary research to help ensure that digital services become tools for transforming** food, land, and water systems. CGIAR must claim a role in **guiding the research, building reference data assets and supporting analytic services, and facilitating the human-centered co-design of digital solutions.** Partnering with public, private, and non-profit stakeholders, CGIAR must help **accelerate the development of and reduce the commercial risk associated with creating inclusive digital services.**	CGIAR must continue to **link its internal information and data systems with public information systems** to develop greater organizational and sector intelligence and provide timely, trusted knowledge products and intelligence. It will also help **build decentralized and open multi-stakeholder governance to foster the responsible collective action and innovation needed to drive the transformation of food, land, and water systems.**
Outcome statement: The sharing and exchange of well-described, reusable data bridges research domains; enables new insights, solutions, and cross-cutting alliances for research delivery in countries, regions, and landscapes; and accelerates food-security research and innovation.	**Outcome statement:** CGIAR builds a dynamic, unified capability to apply AI, integrating satellite imagery, sensor data, digital technologies, and traditional and non-traditional research data to dynamically model whole food, land, and water systems and to help guide its partners and the sector to more impactful, sustainable, and responsible actions.	**Outcome statement:** CGIAR research data, evidence, and analytics are used by partners to create digital services that reach tens of millions of farmers and small, medium, and large agri-food sector businesses; support greater coordination in the digital agriculture sector; and build resilient, agile food systems able to recover from various shocks.	**Outcome statement:** CGIAR facilitates data-driven, global collaboration across the public, private, and non-profit sectors to achieve the SDGs; supports greater sector transparency on global progress toward the SDGs; and provides timely, trusted data and analysis to guide global collective action and innovation.

DIGITAL INTERVENTION AREAS IN THE 2022-2030 RESEARCH PORTFOLIO

These digital intervention areas intersect naturally with the overall CGIAR research cycle and serve as a means of enhancing alliances in countries, regions, and landscapes targeted in the Research Strategy. They also support and enhance the design and delivery of research that spans CGIAR research domains and impact areas:

RESEARCH DESIGN

The co-design phase of new research initiatives is a critical time in which we can **harmonize research processes, agree on data assets needed and to be created, and coordinate with key stakeholders** in advancing digitally-enabled research. These stakeholders will define common data standards, management, and sharing protocols that will support research and impact objectives aligned with national and regional development strategies for the agricultural sector, identify key analytic questions to answer, and help forge the alliances that will be needed to move insights into action.

ANALYSIS:

Applied, responsible AI will be a key tool used to accelerate the generation of timely analytics that balance environmental, socioeconomic, biodiversity, and conservation goals.

RESEARCH DELIVERY:

Broad engagement to build and leverage **robust, human-centered digital innovation ecosystems** will provide new avenues for CGIAR efforts to effect positive changes in food, land, and water systems; new digital services will become critical tools that can be applied to various complex human needs and development challenges.

DRIVING TRANSFORMATION IN FOOD, LAND, AND WATER SYSTEMS:

Enhanced **digital trust** will help deepen sector intelligence and align public, private, and non-profit actors around the **responsible collective actions and innovations** needed for specific, appropriate, and meaningful transformations of food, land, and water systems.

STRENGTHENING THE DIGITAL FOUNDATIONS OF ONE CGIAR

CGIAR conducted a wide-ranging internal assessment of the state of its digital strategy and the maturity of its use of data and digital technologies.[1] This, together with additional strategy research conducted in 2019 and 2020, contributed to the development of a high-level recommended action plan structured according to five well-established success factors of digitally-enabled organizations:[2]

Provide agile and digital-savvy leadership. Senior leaders will champion a digital strategy that highlights CGIAR's strengths and develops CGIAR's technical leadership in the digital agriculture space. The strategy highlights clear, actionable ways digital technologies can serve the overarching goals of the organization, including implementing cross-cutting digital research innovations to transform food-security research, building internal digital skills and capabilities, and strengthening digital innovation strategy and management in research delivery. Senior leaders will clarify decision-making authorities as well as information policies, standards, systems, and services. They will also provide change leaders in the organization with sufficient authority to implement overall digital governance.

Foster digital ecosystem thinking. The digital revolution unfolding in economies and societies worldwide is driven in large part by a common business model: the digital platform. Digital platforms are multi-sided, technology-enabled networks that facilitate stakeholder interactions. CGIAR is also a multi-sided network; it is well-positioned to leverage its global partnerships, data infrastructure, and domain expertise to serve as a trusted intermediary in the increasingly digital field of agricultural research for development. CGIAR must build on its legacy of multi-stakeholder governance to develop internal- and outward-facing digital innovations, communities of practice, and data or analytics services capable of driving progress toward the SDGs.

Mobilize data and access management. CGIAR must invest in capturing the full value of the data it generates, accelerating multi-disciplinary research needed to advance the food, land, and water system changes the organization seeks to effect. Validated, good-quality data assets spanning CGIAR research domains will become a central component of new digital innovations in research and the basis for new partnerships for research delivery and impact. Internal communities of practice will be empowered to develop and apply data standards and processes to ensure that CGIAR data assets, as well as those of its partners, are open and FAIR. Decision-making authority will be defined to ensure that these standards are validated, adopted, and used in accordance with a clear, unified organizational policy.

Build a forward-looking skills agenda. Keeping pace with the rapid evolution of technologies in digital agriculture will be a significant challenge. CGIAR must address this by articulating a clear digital skills agenda that includes recruiting; accessing skills through new partnerships; developing a pipeline of visiting computer science master's and doctoral candidates with universities; and creating new organization-wide training opportunities.

Design a unified, capability-driven information infrastructure. CGIAR must build a more unified digital vision and governance that guides its infrastructure investments to support the overarching goals of the organization. This will include investments supporting operational excellence, such as adopting common security practices and designing unified or interoperable digital services for administration (e.g., enterprise resource planning). This digital vision will also support research discovery and delivery through facilitating increased access to data services, storage, and computational resources for researchers and enabling information technology (IT) services departments to partner more actively with research informatics teams in the development of new digital methods and cross-cutting digital capabilities for research. CGIAR must engage key internal communities of practice to map its existing IT practices, standards, and investments; it will link these through unified governance and a One CGIAR digital infrastructure roadmap.

MISSION-DRIVEN DIGITAL INNOVATION STRATEGY AND MANAGEMENT

Innovation at the intersection of digital technologies and life sciences is driving rapid changes in food-security research and in countries where CGIAR works. To stay abreast of and guide this rapid digital evolution in the agricultural research-for-development sector, CGIAR must integrate and accelerate good digital practices across the organization and its research portfolio and mobilize the data, analyses, and alliances needed to source and foster the most appropriate digital innovations that support its contributions to the SDGs.

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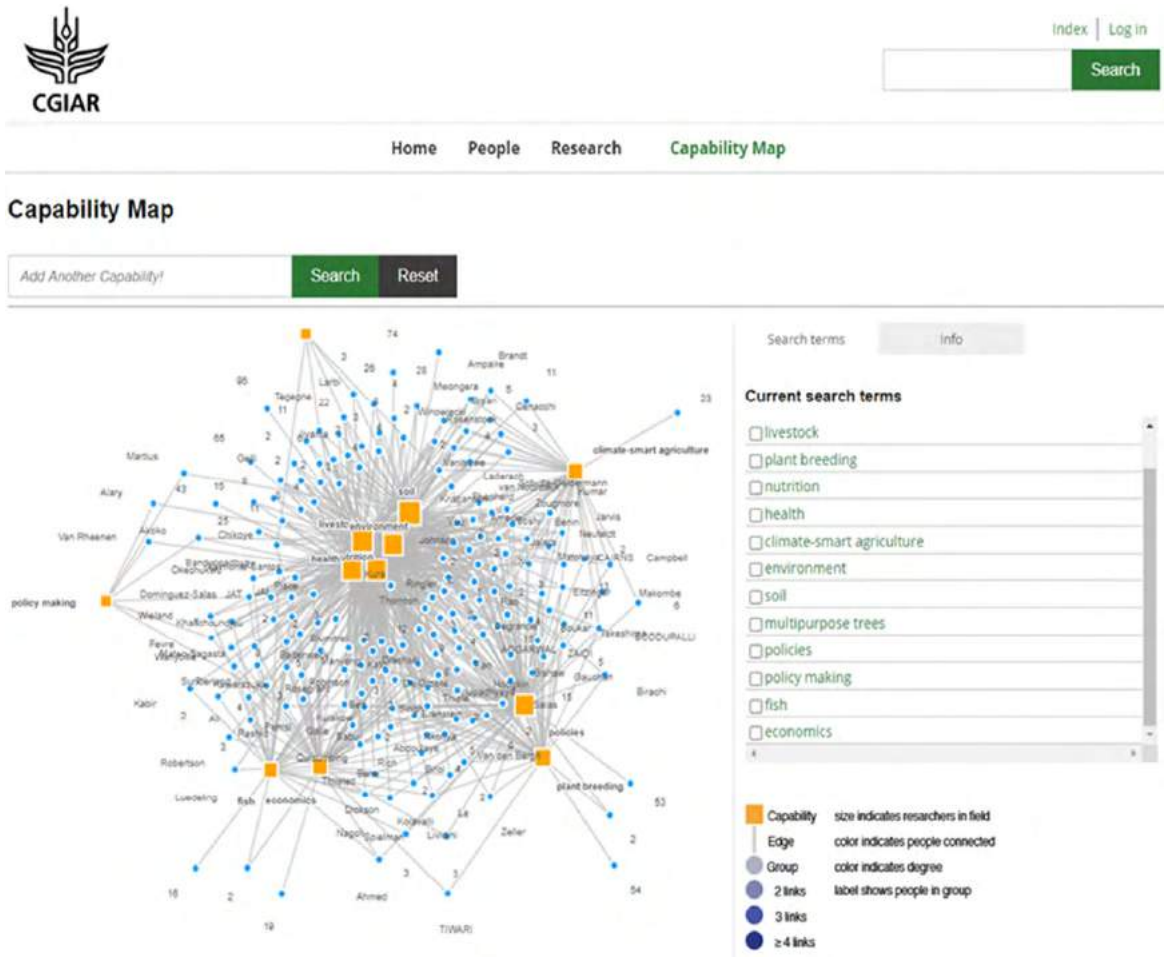
INTRODUCTION: TOWARD A DIGITAL ONE CGIAR

Our world is facing complex, interconnected challenges that threaten not only the natural world and the climate, but also our lives and livelihoods. The window of opportunity for mitigating or reversing the most harmful effects of these challenges is quickly closing and the coming decade could be a critical turning point. In recognition of these increasingly intense, interlinked challenges, the global research consortium CGIAR is restructuring itself to build a more integrated global organization ("One CGIAR") that fully leverages its strengths and refocuses its research strategy through 2030 in service of a renewed mission: *End hunger—through science to transform food, land, and water systems in a climate crisis.*

CGIAR is uniquely placed to address these global challenges. There is no other research organization that has the deep subject-matter expertise in virtually all aspects of food-security research (Figure 1), trusted global partner networks, infrastructure, and presence on the ground in more than 100 countries needed to facilitate work across the spectrum of scientific discovery through to integrated research delivery and engagement with millions of small producers and food-system actors. CGIAR has a strong track record in leading inter-disciplinary research that combines the biophysical and social sciences to combat poverty, hunger, and environmental degradation[3]—which will be essential in addressing the complex, potentially devastating problems facing humankind.

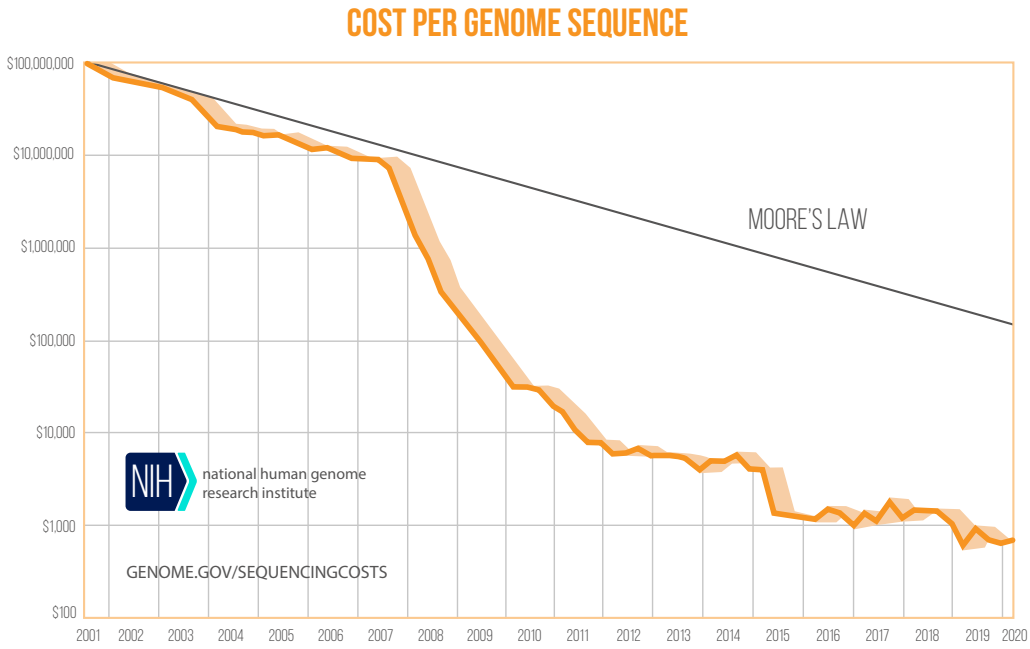
Figure 1. CGIAR leads inter-disciplinary research and generates data in almost every aspect of food security research.



Source: CGIAR http://expertfinder.cgiar.org/

Innovation at the intersection of the life sciences and digital technologies is occurring at unprecedented rates, creating some of humanity's most potent tools for building sustainable and equitable global food security. Rapidly evolving gene sequencing[4] and phenotyping technologies, in addition to growing access to ever-increasing computational power, are making it possible to target CGIAR food-security interventions to "different, and changing, climatic and agroecological conditions."[5] Steady advances in the speed, capability, and cost-efficiency of computing technologies have helped dramatically drive down the cost of whole-genome sequencing from the turn of the century to 2020,[6] as evidenced by advances in sequencing human genomes (Figure 2). Access to and the use of sequencing technologies are expected to grow through 2030 and beyond. When complemented with continued improvement in analytic methods, these technologies will propel innovation in the life sciences in support of the SDGs.[7]

Figure 2. Steady improvements in the speed and cost-efficiency of computing resources have helped dramatically drive down the costs of whole-genome sequencing in the last 20 years, as evidenced by human genome sequencing.



Source: National Institutes of Health

Rapidly expanding access to and use of connectivity, digital services, remote sensing, computation, and AI have provided new methods for leveraging data to tackle complex sustainability problems while balancing environmental, socioeconomic, biodiversity, and conservation goals[8] in food systems. As economies and societies worldwide become more connected by digital technologies and services, a deluge of data is generated. In turn, this creates new opportunities for building a more nuanced, timely understanding of the world and for deploying digitally-enabled agricultural services that reach even the most vulnerable populations.

This global expansion of digital tools and services also creates both opportunities and risks for agricultural research for development. Data and digital tools are becoming essential for participation in rapidly digitizing economies and managing and accelerating innovation, and are used increasingly throughout most of the world. However, access to digital tools and services is expanding at different rates for different demographic groups: youth tend to lead in adoption; access and use for women and girls is expanding slowly and unequally compared with men and boys; and the growth in access in developing economies is generally much slower than in developed economies.[9] The investment in new data-driven technologies for food security tends to target industrialized farms and their supporting institutions in developed economies. These trends increase the risk of widening social inequity in global food systems. A unified, digital CGIAR must play an important role in shaping how these technologies are used in guiding global food, land, and water systems toward more favorable futures by 2030.

DIGITAL TRENDS AND GLOBAL FOOD SECURITY

DIGITAL TRENDS AND GLOBAL FOOD SECURITY

In 2019 and 2020, CGIAR conducted wide-ranging consultations and internal assessments to better understand how trends in the access to and use of digital technologies may affect global food security; the roles public-interest actors should play in leveraging and shaping these trends; and the unified capabilities CGIAR must cultivate to fully leverage digital technology in the transformation of food, land, and water systems in a climate crisis.

This pointed to four key digital trends that have the potential to transform global food security in the coming decade:

- Data sharing and exchange;
- Artificial intelligence;
- Digital services; and
- Digital trust and collective action.

DATA SHARING AND EXCHANGE:

DATA SHARING IS BECOMING MORE CRITICAL, AND MORE NUANCED

A majority of interviewees participating in the CGIAR strategic research noted an increasing ***unmet demand for data.*** The issue is not a lack of data, as rapidly digitizing economies and societies are creating a ***deluge of digital data;*** rather it is a matter of **poor access** to data and a limited ***adoption of data standards*** to facilitate access to and use of the data, coupled with a need for more mechanisms for data sharing. This includes the ***responsible sharing or use of restricted data*** as well as using proprietary data or anonymized personal data as needed to solve agricultural development problems. A majority of interviewees noted that partnerships are a key means by which they access agricultural data (or aspire to), yet they find it difficult to identify and cultivate strategic partnerships because the industry suffers from significant ***fragmentation,*** characterized by a large number of non-dominant players among which there is a poor information flow.

Demand for data is not new. Open-data policies began to gain popularity more than a decade ago in an effort to address this demand, leveraging the Internet and digitized knowledge in an attempt to create a global "knowledge commons".[10] The research community refined this vision in the form of implementing standards to enable scientific data to be more useful for human and machine use, calling for data to be "FAIR". Adoption of the FAIR Data Principles for open data is advancing inexorably in life sciences research.[11]

The "knowledge commons" vision for agriculture is a compelling one. Providing ready access to standardized and reusable genomic, phenomic, agronomic, environmental, and socioeconomic data at multiple scales could reduce duplicative efforts, spark new alliances, provide new mechanisms for ensuring research reproducibility and quality, and accelerate agricultural research and innovation. This vision is becoming a reality, but more than half of the digital strategy interviewees stated that it is not happening sufficiently fast to meet a rapidly increasing demand for data. More than half of the experts interviewed by CGIAR specifically said that access to quality data was a critical constraint limiting their ability to conduct the necessary analyses to derive insights or develop new products and services to put these insights into action.

> "There are many fields of knowledge that need to come together to build the Good Data future."
>
> Daly, A., Devitt, S. K., & Mann, M. (2019). Good data. Amsterdam, The Netherlands: Institute of Network Cultures.

There are several contexts in which data access may need to be restricted to some degree, such as to protect the privacy of human subjects; to comply with policies and regulations; or to restrict access to intellectual property. The systems, policies, and business models for sharing such restricted data are still emerging,[12,13] and there has been a significant erosion of public trust in recent years regarding responsible access to and use of agricultural data.[14] Given the complex stakeholder relationships to be navigated, access to digital agriculture data may remain very fragmented until effective, responsible mechanisms for sharing restricted data are developed. Until this happens, the critical global analyses needed to guide food, land, and water system transformations will remain fragmented and constrained by a lack of data.

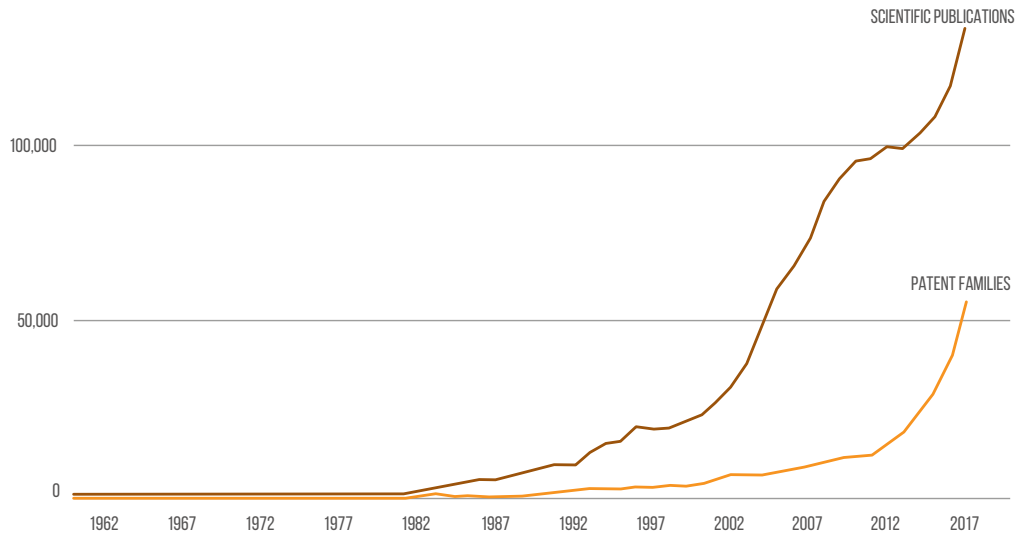
ARTIFICIAL INTELLIGENCE: AI APPEARS POISED TO RADICALLY TRANSFORM ECONOMY AND SOCIETY, YET ITS RESPONSIBLE USE IS STILL POORLY UNDERSTOOD

There is a growing consensus among researchers and economists[15] that ***AI is the next general-purpose technology*** (such as the internal combustion engine and electricity) that will affect

all aspects of the economy and society. However, ***AI is advancing more quickly than are the ethical or regulatory frameworks*** guiding its responsible use.

Computer science intersects with many aspects of agriculture including: precision agriculture technologies,[16] human-computer interactions in agricultural advisory services,[17] even in the assessment of sustainable models for farm connectivity.[18] While technically part of computer science, AI[19] is a technology approach that merits special consideration. According to the World Intellectual Property Organization (WIPO), the number of AI-related patents is increasing rapidly: more than half of all the identified AI-related inventions have been registered since 2013. While scientific publications on AI date back to the 1950s, WIPO notes a boom in publishing on AI topics started around 2001. A surge in AI-related patent applications occurred 12 years later. The ratio of scientific papers to patent applications decreased from 8:1 in 2010 to 3:1 in 2016 – indicating a shift from formulating the theory of AI to its application in commercial products and services.[20]

Figure 3. AI patent families and scientific publications by earliest publication year. AI patent families grew by an average of 28 percent and scientific publications by 5.6 percent annually between 2012 and 2017.



Source: WIPO Technology Trends, 2019 –Artificial Intelligence

AI now touches virtually every aspect of both the global economy and society;[21] more than half of the strategy research interviewees noted that some combination of AI, proximal and remote sensing, and cloud and edge computing will be among the transformative technologies for agriculture in the coming years. AI is both an area of rapid technological innovation and a critical tool for managing innovation. It is already changing how agricultural research for development is conducted and has been identified as a potential enabler of nearly 80 percent of the targets and indicators specified under the SDGs.[22] For these reasons, the One CGIAR research strategy must encompass AI if the organization is to achieve its goals in the coming decade.

AI is already being applied in support of key impact areas in the CGIAR 2030 Research and Innovation Strategy, including assessing and addressing the climate-change impacts of industry,[23] conducting remote sensing-based land-use classification,[24] revealing the characteristics of landscapes on a massive scale,[25] studying complex sustainability problems,[26] managing the interface between expert knowledge and autonomous agricultural systems,[27] and predicting poverty.[28,29]

Most applied AI research published through early 2021 is conducted by a handful of institutions in developed economies in which there are existing, strong AI research capabilities.[30] As a result, the control, development, diffusion, and adoption of this technology will likely favor industrialized economies in the coming decade.

Figure 4. The global rate of adoption of transformational technologies has accelerated in the last two centuries.

Source: Comin, D., & Mestieri, M. (2014). Technology adoption and growth dynamics. National Bureau of Economic Research, working papers.

Participation in the evolution of AI is becoming less linked to location. The surge in AI patent applications noted around 2015 coincides with an uptick in machine-learning-related labor in developing economies; much of this labor consists of outsourced repetitive tasks (such as image classification) with little explicit linkage provided to the to the resulting AI products and services.[31] The design and applied use of AI systems, however, is growing rapidly in developing economies as well. The global technology consulting firm Gartner predicted in 2019 that the number of "citizen data scientists" [32] worldwide can be expected to grow more rapidly than professional data scientists and this appears consistent with significant global growth in use of data science open competition platforms. [33] 2021-2025 could be a critical period for shaping the development of this technology in support of the SDGs in developing economies.

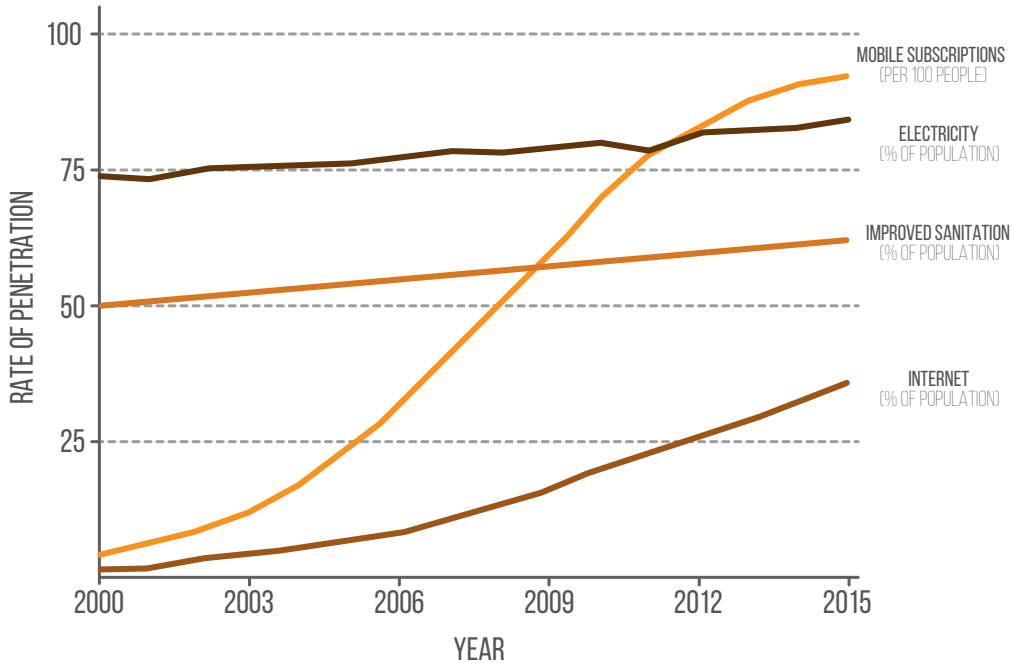
However, the possible risks associated with the widespread use of AI in food security are only now beginning to be examined.[34] In the absence of frameworks guiding its responsible use, widespread application of AI may well exacerbate social differences and sustainability challenges. The opacity or "black box" nature of some approaches can make it difficult to replicate AI-driven research in the lab,[35] and AI faces persistent challenges associated with translating laboratory results to application in the much-more-complex world outside the lab.[36] Challenges with interpreting and explaining the outputs from its models make it difficult to regulate AI—or even anticipate its risks—effectively.[37] AI systems can easily reflect human biases in underlying training data, in AI system design, and in relation to social groups.[38] Unanticipated, cascading system failures have been shown to arise from the *interaction between* AI systems[39] happening faster

than humans are able to respond,[40] and, as digital tools begin to permeate all aspects of agriculture, the risk of such "flash crashes" of the type seen in the financial sector increases. When and if these appear in agriculture, they could accelerate or exacerbate the risk of widespread ecosystem failures in the natural world. Context-specific policies, regulations, and ethical frameworks are needed that can help prevent any unanticipated negative consequences associated with the widespread use of AI—yet these have proven elusive.[41]

DIGITAL SERVICES: RAPIDLY EXPANDING CONNECTIVITY IS CREATING NEW OPPORTUNITIES TO REACH EVEN THE MOST VULNERABLE POPULATIONS WITH DIGITAL SERVICES, BUT THE MODELS AND APPROACHES NEED FURTHER DEVELOPMENT

Expanding global access to telephony and the Internet opens new ***opportunities for creating digital agriculture services to reach even the most vulnerable populations***; however, ***commercial sustainability is a challenge*** and, as a result, rural or low-income populations are rarely engaged in the ***co-design of human-centered digital solutions*** to serve their needs.

Figure 5: The spread of mobile phones relative to other services in low- and middle-income countries.



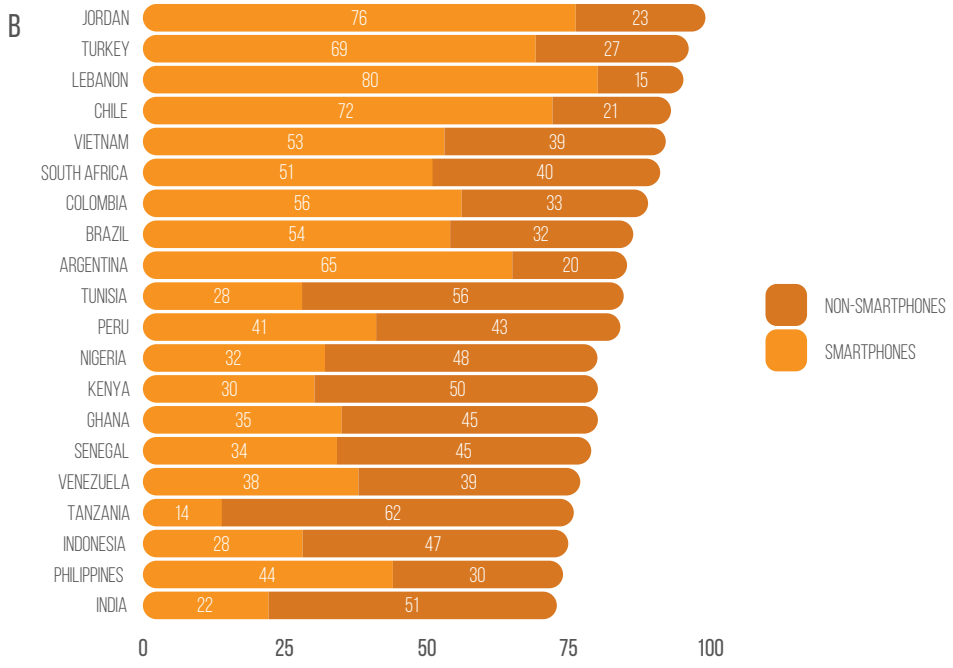
Source: Fabregas, R., Kremer, M., & Schilbach, F. (2019). Realizing the potential of digital development: The case of agricultural advice. Science, 366 (6471).

Successive generations of farming technology in industrialized economies have tended to benefit larger farms and contributed to farm consolidation.[42] Digital farming technologies appear to be developing along a similar path—with the added dimension of increasing the value and desirability of on-farm data[43]—even as their expansion and adoption creates opportunities for new, disruptive business models to arise in developing economies.

The global spread and increasing market penetration of mobile phone connectivity is creating opportunities to deploy digitally-enabled agricultural services able to reach even the most vulnerable populations.[44,45,46] However, there are several significant challenges that still need to be addressed to drive the development, diffusion, and real adoption and use of such services.[47,48,49] There are an estimated 400 million to 500 million smallholder households worldwide, but, in most countries, an overwhelming majority of these households remain unserved by Internet and mobile telephony providers.[50,51]

Agricultural households have a great diversity of characteristics and complex livelihoods of which agriculture is only a part.[52] Poor digital access, the complexity and diversity of agricultural livelihoods, and the need to reach significant numbers of low-income users just for a service to break even make it challenging for digital agriculture services to succeed purely with commercial financing.[53] Digital agriculture start-ups commonly find it challenging to access the essential domain knowledge (e.g., soil science, agronomy, pest and disease, agricultural markets) needed to engage with the inherent complexity and risk of farming. In many cases, they have insufficient opportunities or incentives that would encourage them to interact with small producers or businesses to design effective digital solutions to meet these potential customers' needs.[54] As a result, rural or low-income populations are rarely engaged in the co-design of human-centered digital solutions that could serve their needs.

Figure 6. Penetration of smartphones as a percentage of total phone subscribers in several low- and middle-income countries.



Source: Fabregas, R., Kremer, M., & Schilbach, F. (2019).

DIGITAL TRUST AND RESPONSIBLE COLLECTIVE ACTION

A ***deluge of digital data and media*** is making it difficult for organizations to establish a trusted voice. The current ***global crisis of trust*** in institutions is driven in part by their use of data and digital technologies, even as ***demands for data-driven transparency, accountability, and sustainability*** increase across global food systems.

Governments, firms, non-profits, and the media are less trusted today than they were 10 years ago,[55] and digital tools and technologies have played a role in accelerating this global erosion of trust. Recent years have seen the rise of large-scale state surveillance,[56] confirmation that human biases can be encoded in automated systems,[57] and massive commercialization of user data that has led governments to enact new data privacy regulations.[58] Building trust—especially digital trust[59]—will be critical for organizational efficacy and relevance of institutions in the coming decade. A majority of the experts interviewed in the CGIAR strategy research noted there is an increasing demand from consumers and citizens for data-driven transparency, accountability, and sustainability from institutions overall, as well as specifically in global food systems.

> "It is no longer enough for companies to say why they deserve consumers' trust; they have to show concretely what they are doing and have the data to back it up."
>
> An interviewee from a global IT and consulting firm

Mature frameworks are emerging for measuring and understanding sustainability in global food systems[60] and these are increasingly being used in information systems to help guide more responsive, data-driven collective action in support of global food security.[61,62,63,64] There is still much to be learned about how to develop digitally-enabled, responsible collective action. Building a global "knowledge commons" may be a foundational step; the vision of such efforts is to create an open, collaborative, community-driven knowledge base to equip humanity with the tools it needs to accelerate our understanding of the world. Community-driven digital technologies and services such as the Internet or open-source software can leverage this knowledge in new digital approaches to collective management and governance of resources in the natural world such as arable land, water resources, and a habitable earth.

Analytic methods that leverage large, high-frequency, unstructured data sources are gaining increased recognition as critical tools for modeling and guiding the interactions between humans, landscapes, and ecosystems[65,66] and for generating the timely insights needed to inform multi-stakeholder governance.[67,68,69] These methods are increasingly applied to critical questions for global food security such as: how can increased information and transparency support the development and adoption of sustainable practices in global agriculture? How can data and digital tools support more agile multi-stakeholder governance aligning public, private, and non-profit investments in support of the SDGs?[70]

STRATEGIC RESPONSES TO THESE EMERGING TRENDS

STRATEGIC RESPONSES TO THESE EMERGING TRENDS

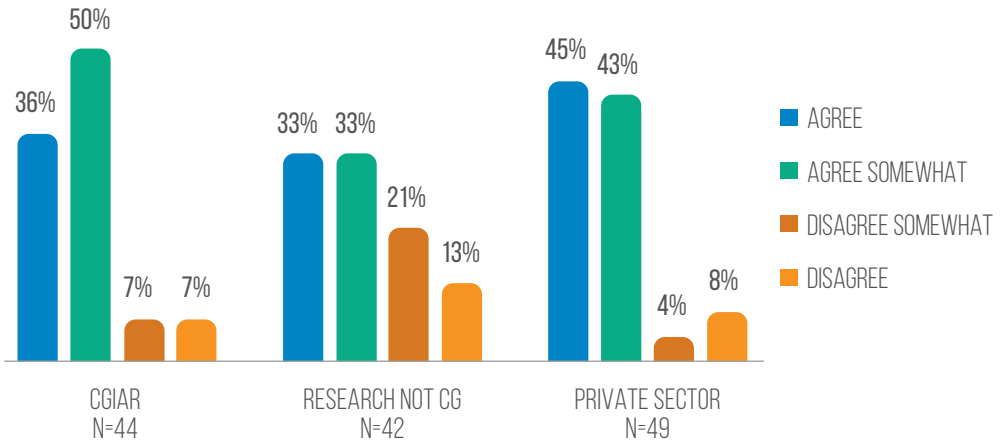
The CGIAR 2030 Research and Innovation Strategy specifically recognizes that the digital revolution is changing how agricultural research for development is conducted and conveys CGIAR's commitment not only to make use of the best tools available for research (e.g., big data analytics and AI), but also to support digitally-empowered end-users in the co-design, access, and use of digital agri-food tools. A unified CGIAR must be well positioned to leverage and shape these digital trends to effect positive changes in global food, land, and water systems.

ENABLE OPEN DATA AND RESPONSIBLE DATA EXCHANGE

CGIAR LEGACY AND CAPABILITIES

CGIAR has made significant investments and progress in building the "knowledge commons" vision for agricultural research for development. CGIAR adopted an Open Access and Data Management (OADM) Policy in 2013, driving a move toward standardized data annotation as well as the storage and reuse of CGIAR research data. [71] An updated policy will be released in 2021, with specific emphasis on the need for CGIAR data assets to be FAIR—a critical mechanism for CGIAR's participation in building a global knowledge base for agriculture.

Figure 7. My organization has a unified view and policy on data sharing, access, and management.



In 2017, CGIAR launched the Global Agricultural Data Innovation and Acceleration Network (GARDIAN).[72] GARDIAN enables all CGIAR data and publication repositories to be searched along with those belonging to a growing group of strategic partners including public agricultural research agencies, development funders, and the World Bank. Each new partner joining up to share data in the network—be it an external strategic partner or a CGIAR program—further reinforces CGIAR's role as a trusted, capable intermediary of open and FAIR data (Figure 9).

Figure 8. My organization's data are findable, accessible, interoperable, and reusable (FAIR).

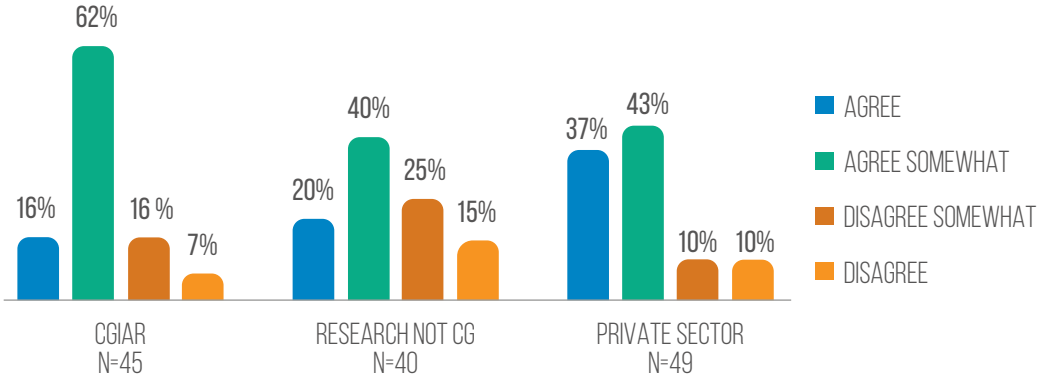
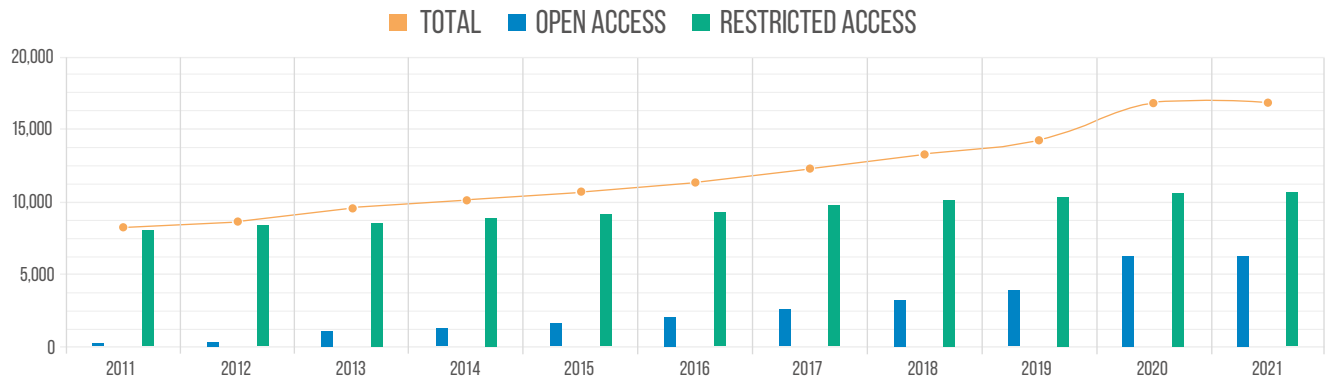


Figure 9. New CGIAR and partner datasets searchable via GARDIAN by year.



Source: GARDIAN, https://gardian.bigdata.cgiar.org/analytics.php#!/ accessed January 15, 2021

According to an internal data management maturity assessment conducted in 2020, CGIAR had achieved a good alignment between its data management practices and its goals, and continued promoting the full adoption and use of those practices across the organization.

SPECIFIC DIGITAL INTERVENTIONS IN RESEARCH

There is an unmet demand for well-described, good-quality agricultural data. CGIAR's global partnership networks and its public-interest mission position it well to become a trusted data provider and intermediary across those research domains that intersect with food-security research and interventions in food, land, and water systems. To more fully develop this role, CGIAR must:

- **Model good scientific data practice throughout the research lifecycle**. Building on its progress in implementing the CGIAR OADM Policy and its contributions to wider standards for agricultural research data, CGIAR must more fully integrate global good practices into the capture, annotation, management, storage, discovery, and reuse of data and serve as a resource to help its partners do the same. CGIAR must continue to contribute to and continually refresh CGIAR and sector-level ethical frameworks for responsible data use consistent with its mission.
- **Build accessible, good-quality, reusable reference data for critical food-security intervention areas.** Accessible, reusable, standards-compliant data for digital agriculture is in short supply and CGIAR is increasingly mobilizing such data. Leveraging—or, when necessary, spearheading the development of—global standards for data capture, annotation, storage, and reuse, CGIAR must invest in building high-quality, interoperable data assets linking genomics, rapid phenotyping, animal and plant breeding, and the socioeconomic, ecological, and climatic contexts of agriculture.
- **Develop the governance and supporting systems for the responsible exchange and use of public, private, and non-profit data for accelerating agri-food research-for-development outcomes.** Sharing data that may be restricted for legitimate

reasons (e.g., digital privacy, policy and regulatory compliance, data sovereignty, or protecting intellectual property) is becoming increasingly important for accelerating digital agriculture and its potential contribution to development outcomes. CGIAR must navigate the evolving policy environment of national regulations[73] and national strategies[74] in the countries in which it works to develop the governance, systems, and models[75] that enable the responsible sharing of such restricted data with an array of stakeholders, building on models from other sectors, such as public health.[76]

- **Build the "good data" future.** Researchers and policy makers commonly seek to anticipate and avert the potential risks of misuse of data (e.g., violating the privacy of human research subjects, legal and reputational risks associated with data breaches). As a result, many organizations adopt a reactive and defensive strategic posture and lose sight of the potential positive effects of a data-rich future. Most experts interviewed during the digital strategy research stated that CGIAR should play an active role in defining a positive digital vision for global food security and build the multi-stakeholder and transdisciplinary engagement needed to create this "good data" future.[77] CGIAR must take an active role in building this future, managing the risks of action and averting the risks of inaction (see Annex 6: Risks of action and inaction).

> "Adopt the concept of data stewardship as a public good [...] when you are stewards, you look at proper maintenance and try to increase the value of data through use, through its integration, through its interoperability. Data acquires value through transactions—it doesn't always need to be fully open— through the sharing of not only proprietary data, but the base data and tools layer as well. Straddle the line between proprietary and shared... Take a critical leadership role in this space—[the] private sector cannot do this, but they can deliver on the solutions."
>
> An interviewee from a breeding informatics startup on the data leadership role CGIAR should play in the agricultural sector

OUTCOME STATEMENTS

- CGIAR data assets are readily discoverable, accessible, and usable by humans and machines, and are increasingly used across the agricultural research-for-development sector, forming the basis for new data-driven partnerships and innovations.
- New alliances with public, private, and non-profit organizations make responsible use of an array of proprietary data and open data, making the digital revolution more relevant to the countries in and challenges on which CGIAR focuses.
- Good-quality, standards-compliant data are made available to enable the best quality analysis and outputs possible from AI systems for agriculture.

DEVELOP RESPONSIBLE AI FOR THE SDGS

CGIAR LEGACY AND CAPABILITIES

CGIAR researchers are applying AI tools[78] in areas as diverse as:

- Predicting soil type and estimating organic carbon from space;
- Monitoring and predicting changes in natural resources and land use;
- Predicting crop yield and loss;
- Mapping and predicting cropping patterns in agro-ecologies;
- Conducting high-throughput phenotyping in breeding operations;
- Enabling genomic breeding selection; and
- Building decision support systems that link traditional knowledge with governance mechanisms for managing natural resources.

Despite the diverse of use of AI by CGIAR researchers, these AI capabilities are limited to a small number of disparate teams across the organization.

CGIAR conducts its AI research in collaboration with various partners. Its researchers tend to team with national agricultural research and extension agencies and technical and research universities.[79] Most experts interviewed in the digital strategy research stated that partnerships were a key means of accelerating the development of AI capabilities in agriculture. Agricultural organizations sometimes struggle to find (or afford) AI talent; even within organizations recognized as global AI leaders, partnerships are critical for accessing deep expertise across the array of research domains that are relevant to agriculture. CGIAR was universally seen as a source of deep domain expertise in agriculture, which could position it well to build a global partnership network for advancing responsible AI use in agriculture.

SPECIFIC DIGITAL INTERVENTIONS IN RESEARCH

AI appears poised to be a transformative technology for the economy and society, and CGIAR is well positioned to help claim its benefits and mitigate its risks in agri-food research for development. Applied research on ethical frameworks guiding its use; policies for its diffusion; the quality, interpretability, and "explainability"[80] of its results; and potential risks of its use in food, land, and water systems will be important CGIAR contributions to the sector. AI can be useful across a wide swath of CGIAR impact areas[81] and global research networks such as CGIAR will be critical for overcoming national disparities in research collaboration,[82] connecting national research networks, equipping a wider swath of food security actors to stay abreast of this rapidly evolving field, and accelerating the responsible, human-driven design needed to leverage AI to meaningfully contribute to the SDGs.

In order to advance AI use for global food security, CGIAR must:

- **Responsibly apply AI to accelerate agri-food research for development and the SDGs.** AI is proving to be a critical tool for leveraging satellite imagery, sensor data, traditional research data, and output from computational models to tackle complex sustainability problems while balancing environmental, socioeconomic, biodiversity, and conservation goals.[83] CGIAR must develop applied AI to enhance the organization's research portfolio and include stakeholders in its design, use, and validation.
- **Continually develop and refresh context-specific ethical frameworks and protocols for AI-driven research.** Universal ethical frameworks for AI have proven elusive and guidelines for the appropriate, responsible use of this technology will likely need to be very context-specific.[84] CGIAR must leverage its global partner networks and participation in agricultural sectors worldwide to develop dynamic, responsive governance around the responsible, explainable use of AI and translate these into specific research protocols for the agricultural research-for-development sector—similar to those emerging in medical research.[85]
- **Develop open alliances for AI innovation.** Cross-domain partnerships bridging computer science and other research domains[86] will be critical for identifying and accelerating meaningful AI innovations for advancing global food security. CGIAR must foster partnerships that support the use of AI throughout the agricultural research for development sector and throughout the organization.

OUTCOME STATEMENTS

- CGIAR accelerates the creation of responsible, human-centered AI applications across CGIAR and the research-for-development spectrum, to dynamically model and predict the outcomes of whole food, land, and water systems and help guide the agri-food sector to more impactful, sustainable, and responsible action.
- CGIAR develops dynamic, responsive governance around the responsible, explainable use of AI, supported by ethical frameworks and research protocols.
- CGIAR develops open innovation for AI, sourcing good ideas for building global food security and leveraging innovation processes and alliances with research organizations and public, private, and non-profit stakeholders worldwide.

> "As the use and impact of autonomous and intelligent systems (A/IS) become pervasive, we need to establish societal and policy guidelines in order for such systems to remain human-centric, serving humanity's values and ethical principles."
>
> The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems

ENABLE AND VALIDATE BUNDLED DIGITAL SERVICES FOR FOOD SYSTEMS

CGIAR'S LEGACY AND CAPABILITIES

The literature reviewed and experts interviewed agree: CGIAR can play a transformative role in accelerating the development, diffusion, and adoption of digital agriculture services. Public-good actors such as CGIAR and national agricultural research and extension services could make upstream investments to help lower the costs of and mitigate the risks associated with the design, deployment, and adoption of these services. CGIAR and its partners could, for example, help build publicly available repositories of validated data and analytics for use by start-ups and private-sector service providers, facilitate the creation and sharing of good practices and open algorithms, and build the evidence base for promising digital business models, such as bundling these types of applications with financial services.[87]

Partnerships will be critical for applying computer science and digital technology successfully in agricultural research for development. CGIAR has deep, multi-disciplinary expertise in the development, adoption, and diffusion of agricultural innovations, particularly in partnership with national agricultural research agencies and extension services, and several CGIAR Centers and Programs[88] have invested in, and continue to invest in, building on this legacy to develop digitally-enabled agricultural advisory services. As a result, CGIAR is well positioned to validate the impact of these tools in food security and evaluate related business models, advance the discipline of applied human-computer interaction in agriculture, build good-quality data and analytic assets to support digital agriculture services, and facilitate the co-design of digital solutions with farmers as well as public, private, and non-profit service providers. This will help localize digital services, drive down the cost of developing these tools and services, and build a digital innovation ecosystem supporting the development and extension of digital services for smallholder farmers and small agri-food businesses worldwide.

SPECIFIC DIGITAL INTERVENTIONS IN RESEARCH

In order to help CGIAR take the fullest advantage of the opportunities such bundled digital services present, it will:

- **Create the needed supporting data and analytic assets to develop the digital services ecosystem.** CGIAR research into topics such as sustainable agricultural productivity, climate risks, natural resources, and ecosystem services generates valuable data and analyses that can be bundled with digital services such as crop insurance, credit, savings, and payment services to reach small-scale producers and agri-food businesses at scale. CGIAR must pursue data standards, collection, curation, and analysis approaches that are fit-for-purpose for product developers, to help decrease the risks and costs associated with the development and deployment of these types of services.
- **Partner with product and service developers.** CGIAR must connect agricultural communities, funding and finance organizations, the mobile phone industry, agri-food companies, and other public, private, and non-profit stakeholders to facilitate and foster the human-centered co-design of digital services for agri-food businesses of all sizes.
- **Build the evidence base for digital food systems.** CGIAR must generate and collate the evidence needed to help practitioners easily identify mature technologies and entry points for their use in agri-food systems and will monitor how emergent technologies and business models are evolving at the intersection of digital innovation and global food systems.

OUTCOME STATEMENTS

- CGIAR research data, evidence, and analytics are used by developers to create bundled digital services that reach tens of millions of farmers

and all sizes of agri-food sector businesses; help unify the sector; and build resilient, agile food systems able to recover from shocks.

- CGIAR helps build more digital links in food systems, building new agility and increasing the capacity of actors to better recover from biotic (e.g., crop or livestock disease epidemics) and abiotic (e.g., extreme weather events) shocks.
- CGIAR accelerates learning across the agri-food sector about the use and effects of digital technologies and business models.

BUILD DIGITAL TRUST AND ENABLE RESPONSIBLE COLLECTIVE ACTION

CGIAR LEGACY AND CAPABILITIES

Trusted public-interest organizations such as CGIAR can play key roles in supporting the collective actions needed to transform food, land, and water systems worldwide. They can provide credible data and information, measure impact and test hypotheses about effecting positive change, and help build the collaboration networks needed to bring this collective action into reality in specific agroecological zones, regions, countries, and landscapes.

CGIAR—a global network organization of network organizations working in the public interest—attracts a wide diversity of views of how best to guide global collective actions. CGIAR has been urged by its diverse global group of stakeholders to make full use of its research partnerships by linking universities and national agricultural research services,[89] building data-driven engagement with small-scale producers worldwide,[90] helping move global agriculture toward agroecological intensification and carbon neutrality, [91] and leveraging its global footprint and vast partner networks to help guide responsible, sustainable action in the agri-food sector.

SPECIFIC DIGITAL INTERVENTIONS IN RESEARCH

Continue to link internal and external information and systems to build trust. CGIAR has information systems for performance-based program management, managing data and intellectual assets,[92,93] identifying research expertise across a diffuse global organization,[94] presenting consolidated information on research products,[95] and disseminating CGIAR innovations.[96] Building on these systems and linking them to external public information systems—such as those centered on genetic resources,[97] funding flows,[98] overall performance,[99] or the SDGs[100] —will provide new opportunities for CGIAR to demonstrate its competencies and model the transparency and ethical behaviors that are fundamentally required for building trust.[101]

Provide timely, trusted, actionable intelligence. CGIAR investments in data standards and infrastructure equip it to provide well-visualized, actionable analysis and insights on food, land, and water systems—including ecosystem health, sustainable agricultural intensification, climate risk and adaptation options, and natural resources—to facilitate greater transparency and increasingly help guide stakeholders in strengthening their own data-driven transparency and accountability.

Build adaptive, open, evidence-driven governance for collective action. CGIAR must participate more actively in global forums and seek to support global organizations such as the World Bank and the Food and Agriculture Organization of the United Nations in gathering and sharing standardized data, assessing development progress, and guiding the global collective actions needed to achieve the SDGs. New, timely, well-presented, and actionable sector

intelligence will inform the development of multi-stakeholder governance mechanisms and highlight the collective actions needed to meet the SDG targets and manage the massive challenges facing global food security.

OUTCOME STATEMENTS

- CGIAR facilitates data-driven global collaboration across the public, private, and non-profit sectors to achieve the SDGs; supports greater sector transparency on global progress toward the SDGs; and provides timely, trusted data and analyses to guide global collective action and innovation.
- CGIAR leverages its global footprint and partner networks to build the agile, adaptive, multi-stakeholder governance needed to guide global collective action.

DIGITAL INTERVENTION AREAS IN THE 2022-2030 RESEARCH PORTFOLIO

The CGIAR 2030 Research and Innovation Strategy outlines three broad "Action Areas" guiding the new research portfolio:

Systems transformation

Resilient agri-food systems

Genetic innovation

These Action Areas will be delivered through three-year investment plans, many of which are expected to target some specific geographic regions that have distinct characteristics and development priorities. The digital intervention areas would intersect with and enhance the design and delivery of research-for-development programs in the specific countries, regions, and landscapes targeted in the research strategy at different stages in the research cycle.

Stages in the CGIAR research cycle:

Research design: As regional stakeholders (national governments, agri-food industry, national agricultural research and extension services, civil society organizations) unite around specific objectives within national and regional agricultural development strategies, collaboration on **data standards, management, and sharing** will enable these actors to mobilize the data needed to measure the current status of those objectives, prioritize research-for-development interventions, and form the basis of more coordinated, data-driven action through regional research-for-development programs. The co-design phase of new research initiatives is a critical time to **harmonize research processes, agree on data assets needed and to be created, and coordinate with key stakeholders** in advancing digitally-enabled research and forging the alliances that will be needed to put insights into action.

Analysis: Leveraging more discoverable, interoperable, machine-ready data (integrating satellite imagery, sensor data, traditional research data, and outputs from computational models), CGIAR and regional stakeholders will **co-design and responsibly apply AI** to generate timely analytics and guide actions that balance the various environmental, socioeconomic, biodiversity, and conservation goals in accordance with national and regional development strategies.

Research delivery: Broad stakeholder engagement in target regions will guide the **development of robust, human-centered digital innovation ecosystems that support digital services in the agri-food sector.** These include developing tools such as large-scale decision support systems, digital financial products targeting the specific livelihoods and climate adaptation needs of vulnerable farmers, and the creation of new business models built on research data and analytics in national and regional markets and agri-food systems.

Driving transformation in food, land, and water systems: Digitally-enhanced data, analysis, services, and collective action will create the basis for continuous learning. Enhanced **digital trust** will help deepen sector intelligence and help align public, private, and non-profit actors around the **responsible collective actions and innovations** needed for specific, appropriate, and meaningful food, land, and water systems transformations.

DIGITAL	SYSTEMS TRANSFORMATION		RESILIENT AGRIFOOD SYSTEMS	GENETIC INNOVATION
Research design	National programs and partners harmonize the research processes and **build a common understanding of the data, digital tools, key stakeholders, and evidence base(s) needed to drive whole-of-system change(s)** while forecasting and planning for scenarios related to climate-change adaptation and mitigation, resource use, and supporting improved livelihoods.		National programs and partners **harmonize the research processes and identify key production and food-system data, digital tools, stakeholders, and the evidence base needed to drive digital innovation** to support resilient, sustainable agri-food systems.	National programs and partners **mobilize data for envirotyping, understanding ecological interactions, and developing demand forecasting and target population of environments (TPE) for crop, fish, and livestock varieties.** Gene banks and breeding programs advance data standards and interoperability to accelerate scientific discovery and genetic innovation.
Analysis	Leveraging more discoverable, interoperable, machine-ready data (integrating satellite imagery, sensor data, traditional research data, and output from computational models), CGIAR and regional stakeholders will **co-design and apply responsible AI** to generate timely analytics and guide actions that balance environmental, socioeconomic, biodiversity, and conservation goals at the national, regional, and global scales.		CGIAR and its partners leverage machine-ready data (e.g., satellite imagery, sensor data, traditional research data, computational model outputs) to **apply AI analyses that balance livelihood and sustainability goals.**	AI tools accelerate data analysis through the development of tailored, AI-enabled analytic workflows and pipelines for informing product profiles, enhancing envirotyping and accelerating genome selection and trait identification, as well as targeting products.
Research delivery	CGIAR partners provide key insights and support the development of the national and regional digital innovation ecosystem for agriculture as well as digital services that that bundle CGIAR data and insights, which can become a key avenue for supporting agile, large-scale climate adaptation across terrestrial, freshwater, and marine ecosystems.		Digital ecosystems supporting agri-food businesses and business-model innovation enable the bundling of CGIAR intellectual assets with new digital delivery mechanisms that help drive adoption of agri-food production practices that balance livelihood and sustainability goals.	Digitized seed catalogs and **digital services enhance national seed systems that are more effective at driving the scaling and adoption of improved crop varieties,** such as through bundling seed with mobile or digitally-enabled financial services and fostering greater transparency and the ability to audit input networks to detect counterfeits.
Transformation in food, land, and water systems	Continuous learning via data, analysis, and the **data generated by digital services builds greater national and global sector intelligence** that is shared and disseminated to guide and measure new multi-stakeholder interventions, collective action, and agile governance. This supports livelihoods and sustains terrestrial, freshwater, and marine ecosystems.	Continuous learning via **data, analysis, and the data generated by digital services helps build the evidence base for digital interventions and accelerates potentially transformational, scalable business models** and the development of mechanisms to support and scale these sector-wide.		CGIAR and its partners continually **build the value of genetic resources through a growing base of data, evidence, and new discovery** that is increasingly **visible and actionable thanks to data interoperability and links to public information systems, helping build a global knowledge base to accelerate and target genetic innovation for building sustainable agri-food livelihoods and terrestrial, freshwater, and marine ecosystems.**


SAMSUNG

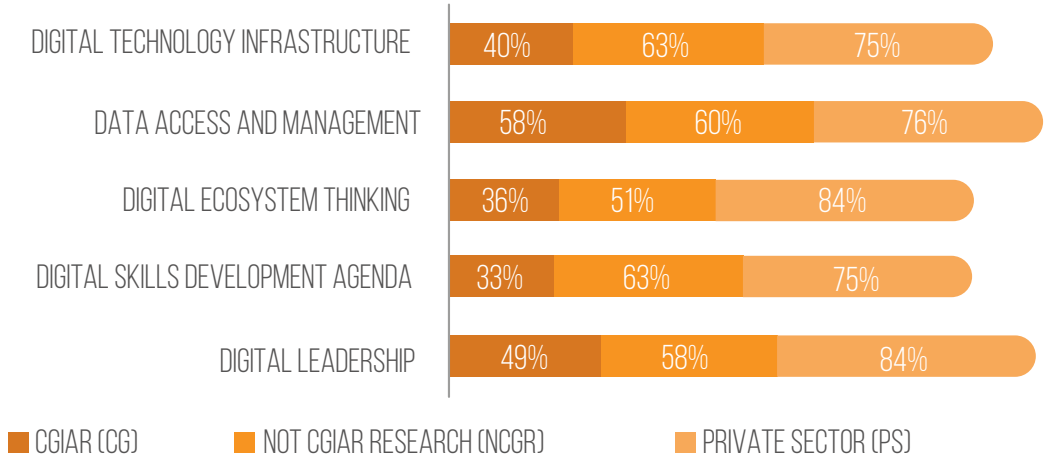
STRENGTHENING THE DIGITAL FOUNDATIONS OF ONE CGIAR

For CGIAR to leverage data and digital tools to their fullest potential in effecting the positive changes envisioned in the CGIAR 2030 Research and Innovation Strategy, it will need to tend to key aspects of its own digital transformation. In 2018-2019, CGIAR conducted a high-level assessment of its digital readiness based on five key enablers of successful digital organizations:

- Agile, digital-savvy leadership;
- Forward-looking skills agenda;
- Digital ecosystem thinking;
- Data mobilization and access management; and
- Technology infrastructure readiness.

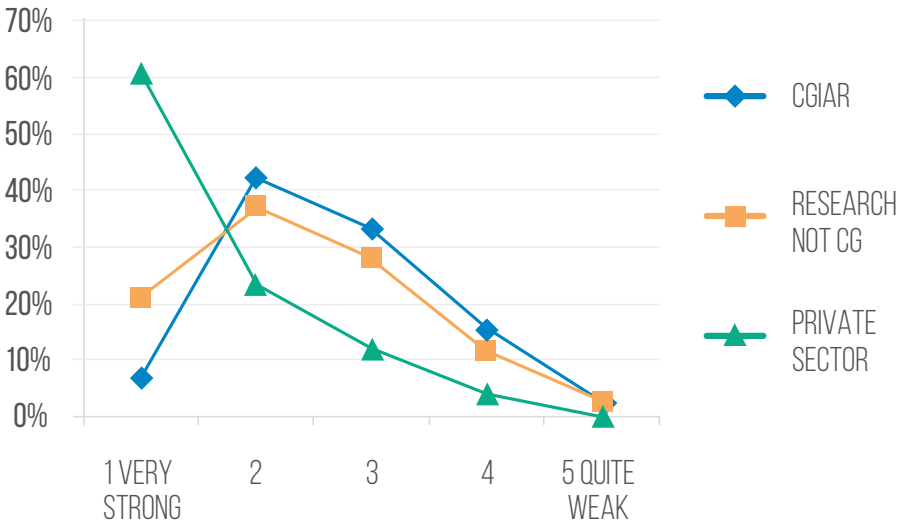
Through these efforts, CGIAR sought to understand the key capabilities and enablers of successful digital organizations in general; how CGIAR compared to other organizations in the agricultural research-for-development ecosystem; and the key priority actions for CGIAR to effective use of data and digital technologies central to its research and daily operations.

Figure 10. Percentage of survey respondents from CGIAR, non-CGIAR research, and private-sector organizations ranking each digital enabler as "strong" or "very strong". Survey respondents from non-CGIAR research organizations generally ranked digital enablers higher in their organization than CGIAR respondents did, and private-sector respondents generally ranked these enablers significantly higher than those from research organizations did.



AGILE, DIGITAL-SAVVY LEADERSHIP

Figure 11. Survey respondents' perceived strength of organizational digital leadership at CGIAR, non-CGIAR research organizations, and the private sector.



THE CHALLENGE

Survey responses and literature research indicate that the single most important feature of a digitally-enabled organization is clear communication from leadership about the organization's digital strategy and how it links to both operations and achieving organizational goals. Senior management at both the center and system levels will need to commit to and clearly communicate such strategic vision and purpose, and guide the organization in attaining the needed skills, engagement, and alignment to execute and achieve such a transformation. A large body of research has found that those entities that have adopted digital strategies closely linked to their organizational strategy are significantly better prepared to navigate digital disruption in their sectors. One important function of a digital strategy is to demystify data and information-technology-related decisions for managers, providing clear tools for linking these decisions to specific digital capabilities and governance the organization needs to have in place in order to deliver on its mission.

KEY INTERVENTIONS

The CGIAR 2030 Research and Innovation Strategy notes that digital innovation will be present in all research and impact areas, and that the digital revolution will be central to how CGIAR operates and conducts its research. The digital strategy will detail the roadmap for setting this in motion under One CGIAR and will establish clear links between digital capabilities and organizational strategy.

Key actions senior leaders should oversee to strengthen digital leadership across the organization include:

- **Validate, finalize, and secure approval of a One CGIAR digital strategy centered on strengthening and linking cross-cutting digital capabilities.** Senior leadership will need to oversee the finalization of a One CGIAR digital strategy within the wider organization and secure approval for it from the Board and System Council.
- **Continually assess and strengthen One CGIAR's digital capabilities.** One central product synthesized from CGIAR's digital strategy research is a map and high-level assessment of the current maturity of those cross-cutting digital capabilities that will be important for building a more unified, digitally-enabled organization. This unified organizational model encompasses the infrastructure and operations of CGIAR as well as its core focus on agricultural research for development. The digital capability model will be a living document used to guide information gathering and continual co-design and coordination on the path to building a more unified, digitally-enabled organization (See Figure 12).
- **Establish one CGIAR digital governance.** Building the digital One CGIAR must require cultivating a diverse array of digital capabilities spanning operations, research, and research delivery. Many of these capabilities will require deep domain expertise to help set the right priorities for each in light of the organizational strategy and to guide decision-making regarding technical and ethical standards for each. (See Figure 8.) Several business units across CGIAR—at both the system and center levels—have a hand in guiding the decision-making processes regarding data and IT investments. These data and digital research governance functions are distributed across CGIAR and are tended to by a variety of platforms, programs, and technical and functional communities of practice (CoPs) and their partners. (See Figure 13).

MATURITY OF CROSS-CUTTING DIGITAL CAPABILITIES

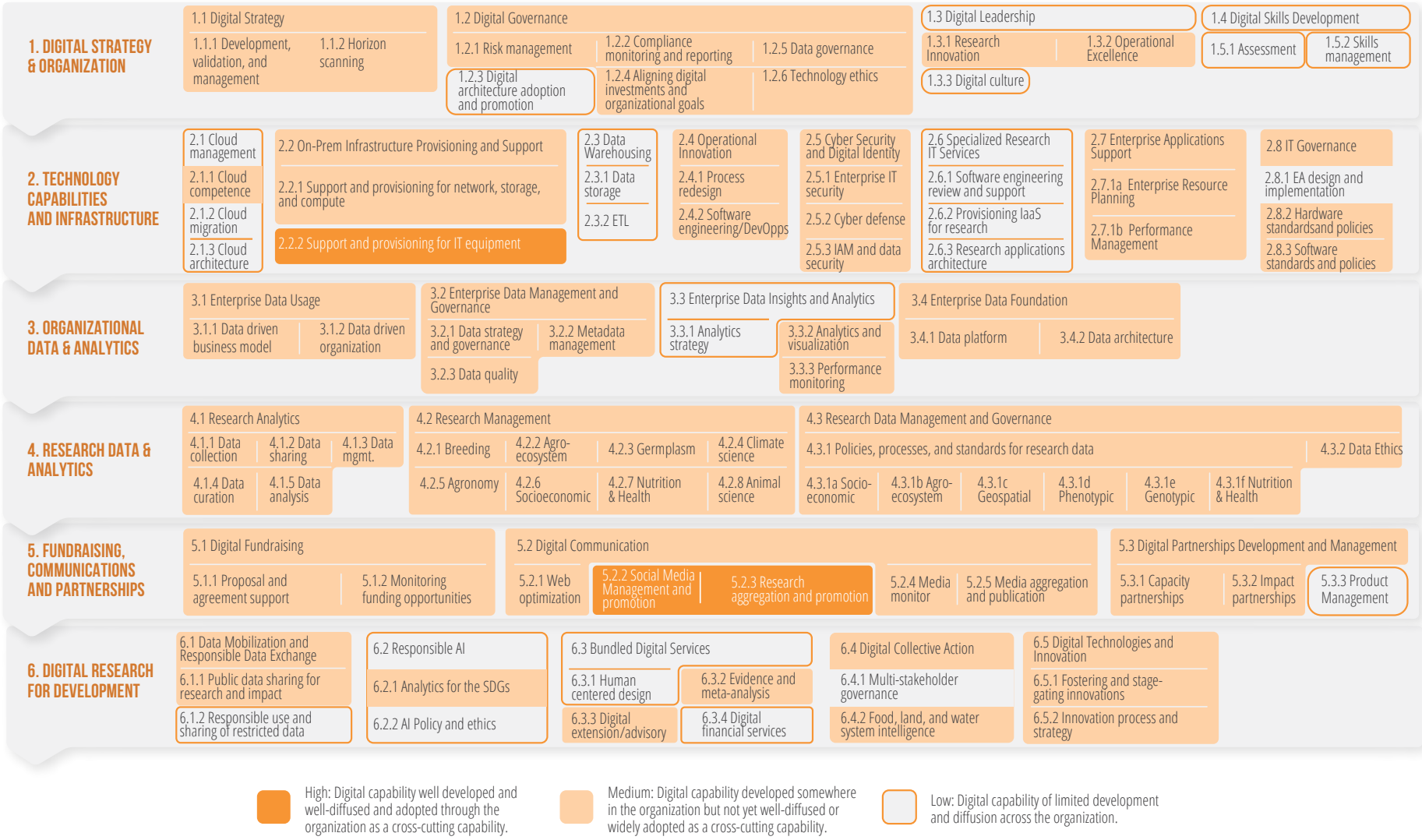


Figure 12. A draft unified One CGIAR digital capability model, which spans the organization's enterprise and research informatics capabilities.

WHAT DIGITAL CAPABILITIES REQUIRE A GOVERNANCE FUNCTION?

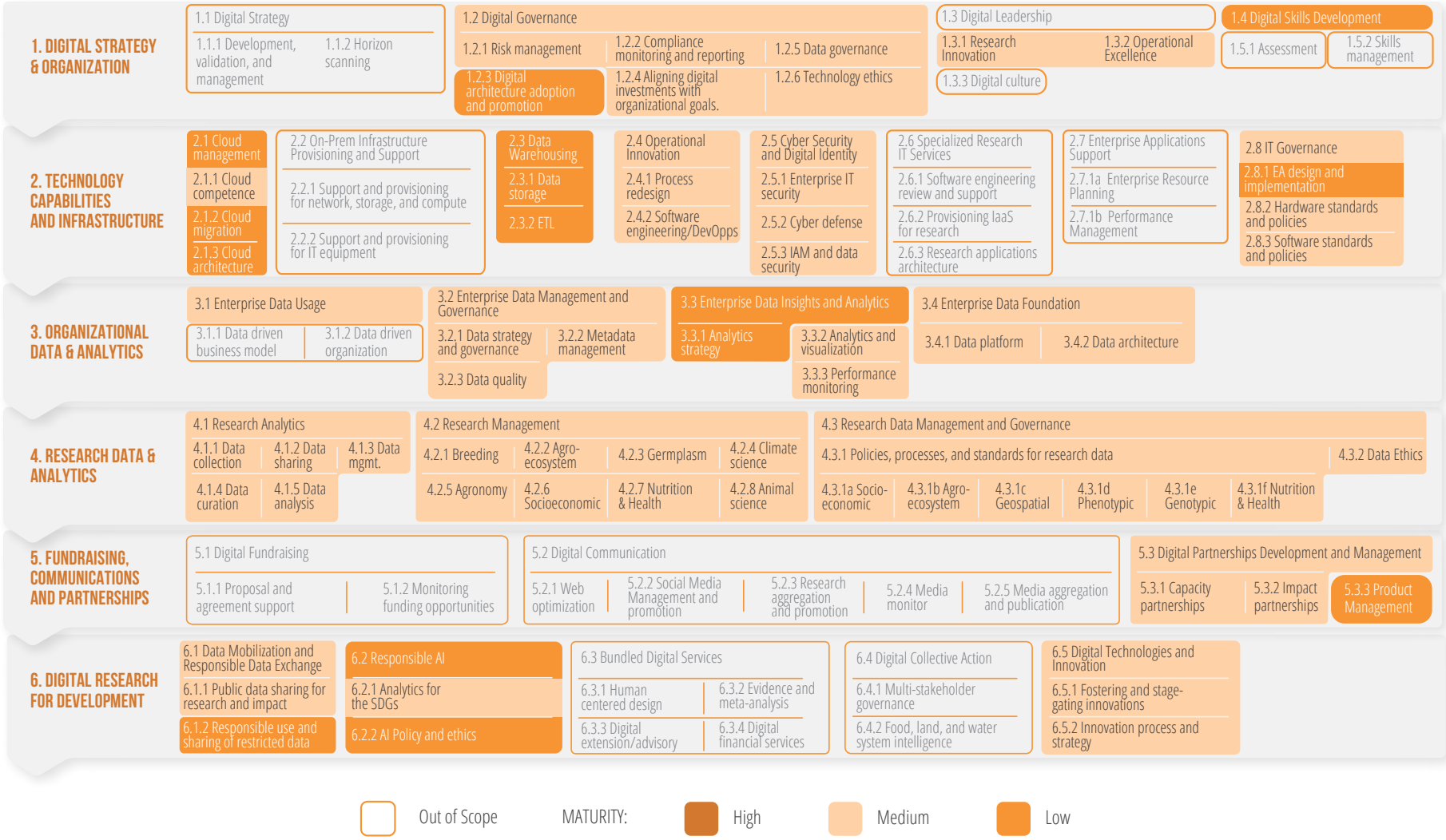
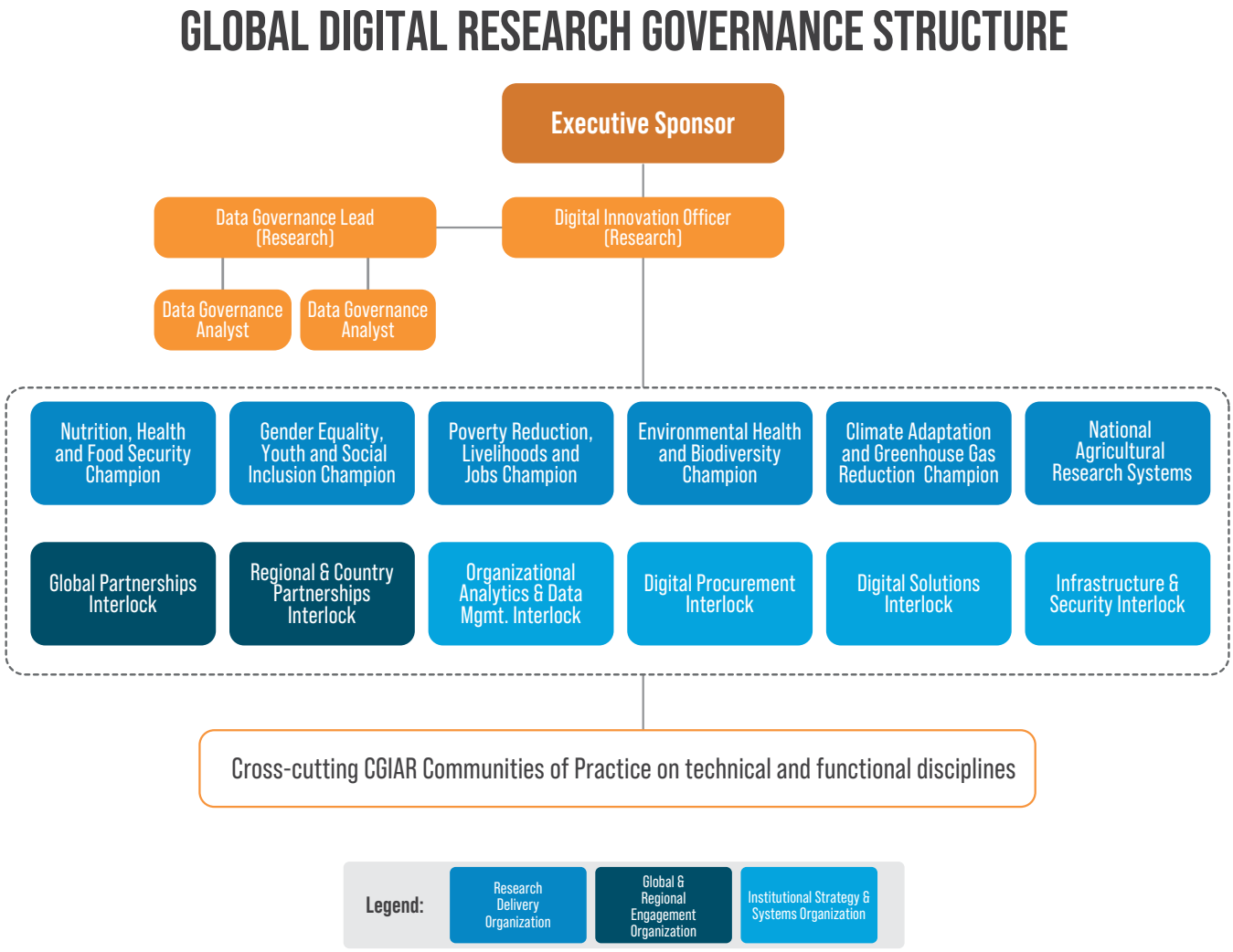


Figure 13. Governance functions required for a unified One CGIAR digital capability model, which spans enterprise IT and research informatics capabilities.

Senior leadership will clarify the governance processes that will harness CGIAR's internal technical depth, define the explicit mandates associated with developing data and IT standards, and clearly define the more formal mechanisms required for the review and adoption of digital policies, processes, and standards. One potential model would be to establish a cross-cutting digital governance body that guides data standards and digital-research innovation and links internal research domain experts, individuals with Digital Services functions, senior leadership, and strategic external stakeholder bodies such as national agricultural research agencies (see Figure 14).

Figure 14. Potential composition and structure of a CGIAR governance entity for guiding digital investments, standards, and innovation in research, harnessing CGIAR domain expertise spanning research domains and mechanisms for research delivery.



Source: CGIAR digital strategy research.

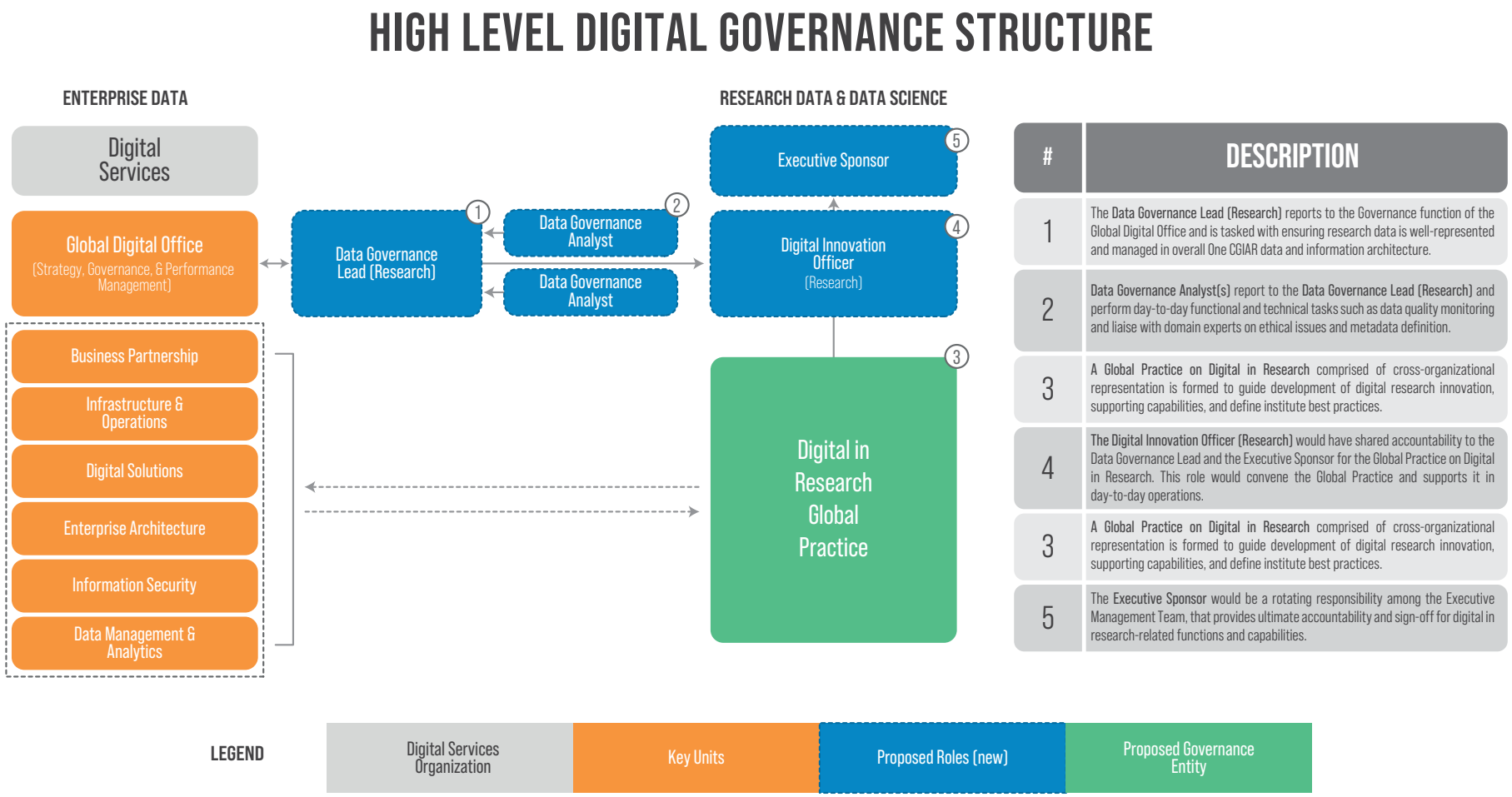
- **Appoint leaders for digital innovation and data governance to guide digital transformation in One CGIAR research.** Implementing inclusive governance will help CGIAR build a more unified organization in which research functions —such as research informatics, partnerships, and digital innovation in research— are closely linked with operational functions such as enterprise management, process automation, and setting common engineering and security standards. Digital transformation in operations and enterprise systems and infrastructure will be led by the Digital Services Unit in One CGIAR. Critical leadership functions needed to drive technology integration and transformation on the research side of the organization include the appointment of a Digital Innovation Officer (Research) and a Data Governance Leader (Research).

- **The Digital Innovation Officer (Research)** would lead and support digital transformation in research informatics across CGIAR; develop new digital pathways to realizing the SDGs; manage the process of identifying and prioritizing key digital services, infrastructure, and policies to implement the CGIAR 2030 Research and Innovation Strategy; and serve as a key intermediary between research informatics and the Digital Services Unit. The Digital Innovation Officer (Research) would have shared accountability to the Director of the Digital Services Unit and to an Executive Sponsor for digital governance in research (See Figure 10).

- **The Data Governance Leader (Research)** would be the intermediary between research data needs, standards, quality, and architectures and the Digital Services Unit. This individual would play a key role in leading the implementation and enforcement of data standards across the research side of the organization and in overseeing efforts to ensure the collection and stewardship of good-quality research data in service of CGIAR's core business of undertaking ethical, replicable, good-quality science in support of agriculture research for development.

The Data Governance Leader (Research) would report to the Digital Innovation Officer and would work with the governance function of the Digital Services Unit/Global Digital Office. This role would be supported by one or more data analysts who would provide technical assistance to initiatives and Science Groups, monitor implementation of data standards, assess data quality, and serve as additional points of contact on good data practice issues across CGIAR's research domains (see Figure 15).

Figure 15. Potential governance structure, including recommended leadership roles for guiding digital transformation in CGIAR research and delivery.



Source: CGIAR digital strategy research.

OUTCOME STATEMENTS

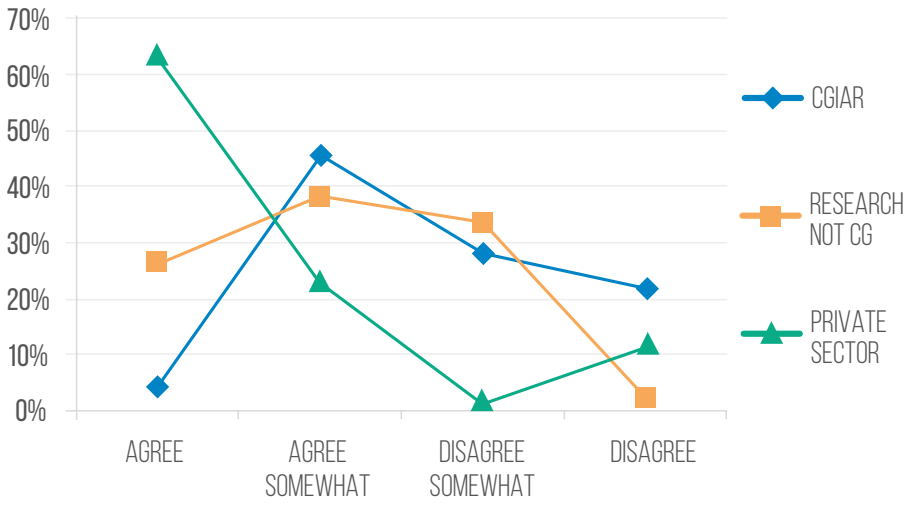
- All One CGIAR initiatives develop more unified, cross-cutting digital capabilities that support implementation of the CGIAR 2030 Research and Innovation Strategy and the shared agenda of One CGIAR.
- Staff at all centers are aware of as well as supported and encouraged to observe good data and information practices and are cognizant of their contributions to the overall delivery of the CGIAR mission.
- CGIAR observes unified policies and governance procedures on data collection, sharing, storage, and use, which are applied across the organization.

FORWARD-LOOKING SKILLS AGENDA

THE CHALLENGE

Digital agriculture is evolving and transdisciplinary. Staying abreast of those data and computer science skills that are applicable to digital agriculture is a significant challenge. Even very large, digital organizations, including global IT firms, often face a gap in accessing the deep expertise required across the life sciences and socioeconomic domains to meaningfully apply computer science for use in food-security applications.

Figure 16. My organization as a whole has a clear agenda to develop digital skills.



KEY INTERVENTIONS

Upskill, recruit, and retain digital talent. Center-based talent attraction and retention strategies will be updated as needed to continue building the organizational digital capabilities that will better equip CGIAR to participate in and navigate among the various digital trends affecting global food security. Centers and the system will identify or develop training content related to maintaining

those core skills that have been identified as being useful across the organization, such as statistical analysis, bioinformatics, and enacting good practices in data management, and in building capabilities in emergent disciplines such as leading-edge computational methods and AI.

- **Incorporate aspects of the digital strategy into staff job descriptions, roles and responsibilities, and performance metrics, and budget accordingly.** Broad-based digital strategy adoption throughout the organization will be critical for the strategy's success. Senior management, research leaders, IT units, human resources professionals, legal professionals, and researchers will have specific, defined roles for implementing the digital strategy, incentivized by performance metrics and supported by appropriate funding. Ownership of the digital transformation will thus be fostered and encouraged throughout the organization.

- **Develop partnerships and engage communities of practice (CoPs) on key digital capabilities.** CGIAR personnel have deep expertise across an array of domains that intersect with global food security and can help CGIAR staff remain abreast of research innovations related to technical or functional digital disciplines through CoPs. These CoPs enable CGIAR to interact with wider technical communities on themes spanning scientific discovery to the uptake and use of research output and serve as a key mechanism to access external research capabilities. Leveraging external partners' computational power, complementary expertise, and perspectives on key technical issues helps embed CGIAR in wide-ranging technical collaborations that can help accelerate the development of responsible, human-driven innovations and help CGIAR access and co-develop the key capabilities it needs to apply these.

- **Develop alliances with computer science faculties.** Digital skills—especially those related to AI—are in high demand. Agriculture is generally unable to match the compensation offered to graduate students by global firms or more digitized sectors such as financial services, but CGIAR can offer them unique and fascinating research opportunities. Young researchers may also be attracted by CGIAR's public-good mission and the opportunity to work on pressing global food security issues. Alliances with universities will enable CGIAR to cultivate and foster early career computer scientists' interest in agricultural research for development early in and, hopefully, throughout their careers.

OUTCOME STATEMENTS

- CGIAR accesses a greater range and depth of data-related skills and leads the development of new digital methods and approaches in the global agri-food research-for-development field.
- CGIAR personnel continually learn and improve their digital skills.
- CGIAR forms and leverages external alliances to access new digital capabilities.
- CGIAR fosters the creation of a cadre of graduate student computer scientists working on science to transform food, land, and water systems.

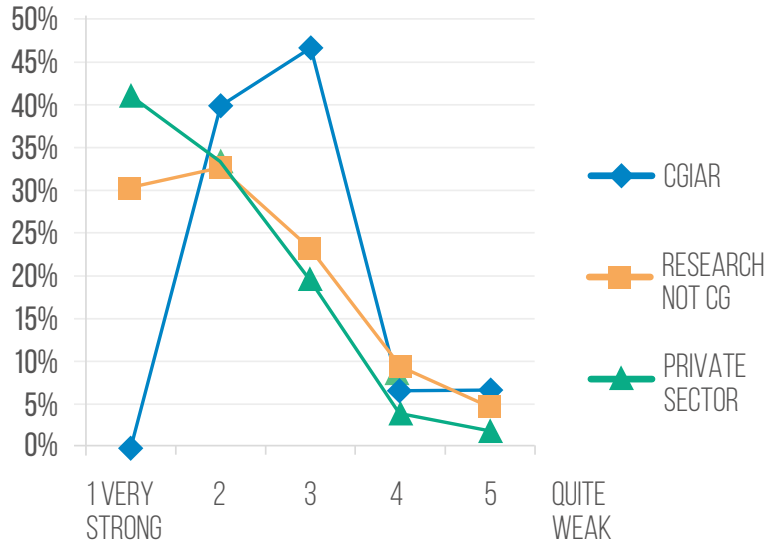
DESIGN A UNIFIED, CAPABILITY-DRIVEN INFORMATION INFRASTRUCTURE

THE CHALLENGE

Many organizations struggle with defining an overarching, integrated vision for guiding digital investments in the service of their strategic goals. For research organizations such as CGIAR, there is very often a division between IT departments that support the organization's functions and research informatics teams that develop or apply digital tools in research. There are a few root causes of this issue:

- **IT services are driven by operational needs, which must be defined, quantified, managed, and measured.** IT departments must navigate significant complexity and an array of competing priorities as they manage core operational services, evaluate technology providers, provide support to

Figure 17. CGIAR respondents were less likely to believe that the CGIAR digital infrastructure supported them in doing their work than did the respondents in other research organizations or from the private sector.



Source: CGIAR strategy research survey.

users of enterprise systems, interact with users who have an array of digital skills, and navigate the complexities of several interlinked systems. To manage this, IT departments typically develop a catalog of services they will provide to other business units. This enables them to keep an eye on costs, to define the appropriate mechanisms for cost-recovery, and to better measure the quantity and quality of services delivered.

Research informatics are driven by science and partnerships. Digital tools and technologies are changing how agricultural research for development is conducted from scientific discovery all the way through to large-scale adoption and use of food-security innovations. As a result, research informatics practitioners are continually seeking to improve—and in some cases, prove—their methods. These efforts are guided by research questions and the research collaborators who join CGIAR, seeking to conduct high-impact research. This often gives rise to the need for computational and informatics resources that are beyond the scope of CGIAR's IT services.

Senior leaders are not typically supported to meaningfully engage on issues related to the organization's digital capabilities. IT management is complex and requires specialized expertise. Similarly, research informatics and data governance can be deeply rooted in the research domains and associated communities of subject-matter experts. As a result, digital leaders often face a "translational" challenge: communicating the strategic importance of digital capabilities for the organization in ways that best equip senior leaders for decision-making.

Developing a digital-capabilities-based view of the organization can help resolve these issues. Using a digital capability model, such as the one shown in Figure 12, can help to reveal the relationships between digital investments and their links to the organization's purpose, and to equip decision makers with a tool to begin to prioritize or coordinate those investments.

KEY INTERVENTIONS

To address this challenge, CGIAR must:

- **Apply cross-cutting capability mapping and assessment to co-design more harmonized and coordinated digital investments in information infrastructure for operations and research.** Data and IT investments will be guided by ascertaining the capabilities needed—what an organization should be able to do—to deliver the CGIAR 2030 Research and Innovation Strategy. The draft digital capability map, seen in Figure 12, can serve as a starting point for refining a shared information vision for One CGIAR. The approach will be applied at a more granular level to map those processes that support important organizational or research functions. This will enable individuals across the organization to better understand where opportunities lie for unifying data assets, aligning stakeholders, supporting critical infrastructure, and developing shared services in support of implementing the One CGIAR vision.
- **Harmonize information infrastructure policies, processes, standards, and services.** CGIAR, led by its Digital Services Unit, will work with centers to harmonize and increasingly integrate IT services, policies, processes, and standards across the organization. The effort will focus on creating the digital capabilities needed to build a more unified enterprise and provide support, as appropriate, for digital research capabilities.
- **Analyze the cost of potential cross-cutting services.** CGIAR must assist centers in assessing the cost-benefit of unifying critical services for research or operations to identify important savings or efficiencies that could be achieved. Conducting a total-cost-of-ownership analysis of vital research and operational capabilities, examining on-site versus in-cloud options within various local contexts, and providing technical support to help move services to the cloud when feasible and cost-effective are also important tasks to complete in order to unify IT services across the organization. CGIAR must work with centers in developing an action plan for gradual transition to the cloud in cases in which such a transition can provide either a cost-savings and/or significant enhancements to the organization's ability to deliver on its mission. It will also help centers in making the eventual transition to the cloud.

OUTCOME STATEMENTS

- CGIAR captures the value of its important, harmonized, cross-cutting services, and facilitates a move toward securing cloud-based storage, computational resources, and data services for enterprise and research use across the organization at a lower total cost.
- The links between IT investments and the key capabilities needed for CGIAR to deliver on its purpose are made interpretable and actionable, in part by equipping senior leadership with new tools for decision making.
- CGIAR operates according to a unified information vision and its supporting infrastructure enhances its ability to engage on global, regional, and national food-security issues and to develop new alliances and innovations for creating resilient food, land, and water systems.

DATA MOBILIZATION AND ACCESS MANAGEMENT

THE CHALLENGE

An overwhelming majority of the respondents who felt that their organization was effective in realizing its purpose noted that the effective use of data was critical to its success. This was true for outward-facing actions, such as using research data effectively, as well as internal actions, such as having data available to measure the efficacy of internal initiatives or business units' performance.

CGIAR uses several performance management, reporting, and management systems and is interlinking these to capture and use data to continually build and refine its business intelligence.

Policies, tools, and processes for research data are advancing as well, but CGIAR still faces challenges in claiming the full value of this data. CGIAR has a wealth of research data, but many of the data sets are restricted, incomplete, or poorly described. They are generally difficult to interpret by either humans or machines and are difficult to aggregate, which consequently makes the application of data science capabilities across large data pools difficult. As a result, CGIAR still struggles to capture the full value of the data it generates, whether for reproducing or accelerating research; developing pan-CGIAR, multi-disciplinary analyses on global issues such as climate change or ecosystem degradation; leveraging data-hungry AI applications; or developing new data-driven products or services.

> "Standardization is the basis for innovation. You can explore anything you want about how to best use drones in [agricultural] research, but you don't get to choose the drone."
>
> An agribusiness executive interviewed in CGIAR strategy research

Internal working groups and business units such as the Information and Data Management or Ontologies CoPs have developed and defined standards for collecting, describing, and storing data that map to widely-accepted standards, but no clear mechanism has been established for these standards to be integrated into a clear pan-CGIAR organizational policy. Lack of a clear decision-making authority on the application of these standards undermines CGIAR's efforts to build a culture of data sharing and reuse as well as hinders its ability to effectively leverage data as an organizational asset.

Harnessing its data will be mission-critical for CGIAR. This will enable the development of replicable analytic pipelines that can be used to leverage CGIAR and partner data around common research themes such as predictive modeling, climate adaptation, biodiversity and ecosystem services, and monitoring and studying changes in the use of various natural resources.

KEY INTERVENTIONS

To address this challenge, CGIAR must:

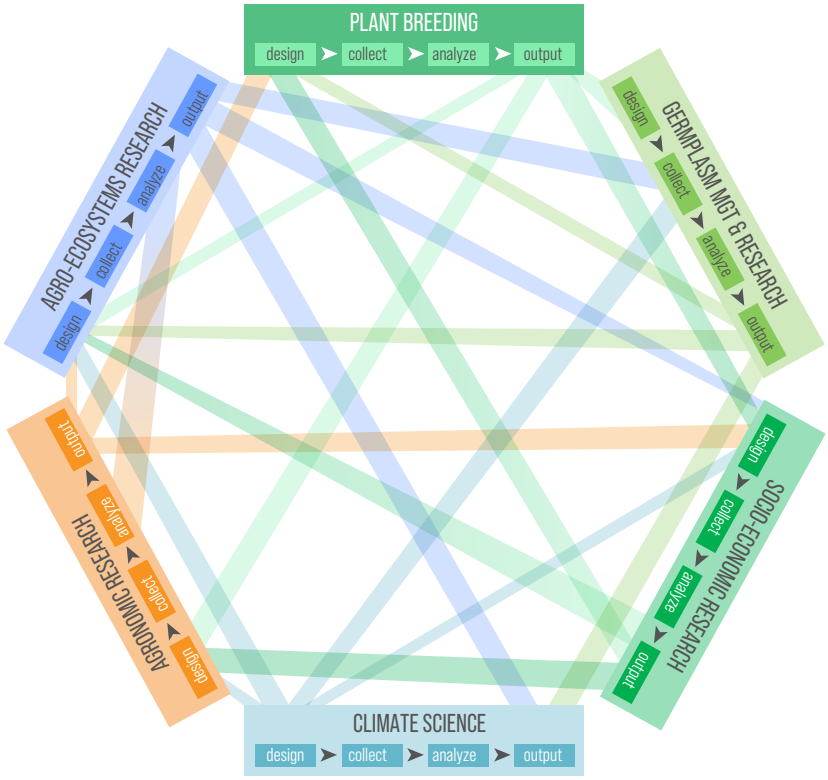
- **Implement recommendations of pan-CGIAR assessments.** In 2020, CGIAR completed pan-CGIAR assessments—including a data management maturity assessment (DMMA) and an internal cybersecurity assessment— each of which offered concrete recommendations for action. The DMMA specifically noted that data management policies exist and recommended that CGIAR continue to invest in the adoption of processes aligned with these policies.

- **Enforce data standards to enable cross-cutting multi-disciplinary research.** Helping CGIAR become a more unified, data-driven research organization will require the adoption and use of common data standards. This should include standards for the sharing, storage, and use of data collections, which will help processes such as data gathering and tagging, for example, to become consistent across CGIAR. Data standards are of fundamental importance to CGIAR's core business of conducting the ethical, good-quality, replicable, multi-disciplinary research needed to guide the transformation of food, land, and water systems.

  The Open Access and Data Management Policy (OADM Policy) was updated in 2020 to reflect the evolving global, community-driven standards for scientific data, such as the CG core metadata schema and the FAIR Data Principles. Its adoption and widespread implementation in the organization can drive significant progress toward mobilizing data

and helping to position CGIAR as a technical resource for those partners wishing to see that their data and knowledge products are more widely discoverable and reused.

Figure 18. Cross-domain links of CGIAR research processes and data as mapped in two regional CGIAR information architecture workshops. Cross-cutting data standards and analytic infrastructure will be critical for pursuing the multi-disciplinary research needed to address interconnected global food security challenges.



Source: CGIAR Platform for Big Data in Agriculture.

Map research processes at the core of the CGIAR mission and build cross-cutting digital-research capabilities. Unified data standards will provide a means for developing new cross-cutting digital-research capabilities. To fully claim the value of interoperable, reusable, available data, CGIAR must begin to harmonize or interconnect those research processes that are at the core of its mission, specifically noting key data assets, digital tools, internal and external stakeholders, and the cross-domain interactions that can be better understood and harnessed through developing more unified research capabilities. The ability to use drone imagery from breeding trials to calibrate remote sensing measurements used in large-scale agronomic or agro-ecological interventions is one example. Such tools could also help capture insights and data from climate adaptation studies and link them to specific seeds—or genomic sequences—in CGIAR gene banks.

Building on the information architecture developed in the CGIAR breeding research domain, CGIAR must continue to map core research processes in other domains and develop replicable analytic pipelines for leveraging CGIAR and partner data around common research themes. These include predictive modeling, climate adaptation, biodiversity and ecosystem services, monitoring and studying changes in use of natural resources.

- **Foster a culture of data sharing and collaboration.** Centers and system leadership will support initiatives that can help foster a data-sharing culture both inside and outside the organization. This might include the development of more integrated, data-driven, pan-CGIAR research efforts on critical global challenges facing food, land, and water systems. This will drive a cultural shift toward the recognition that data collected by individual researchers is a key organizational asset that, when managed properly, reinforces CGIAR's position as a global research organization capable of effecting positive change worldwide. CGIAR must invest in interoperable, interlinked data and consistent data management to effectively translate data into meaningful insights. A key element of these measures will be providing incentives for researchers to share data, e.g., increasing the recognition of those researchers who actively share data and collaborate across the center or the system.

OUTCOME STATEMENTS

- CGIAR researchers leverage shared, interoperable, interlinked data and consistent data management standards and practices to generate timely insights into global food-security challenges and the collective actions needed to solve them.
- All CGIAR business units make increased use of a common pool of well-validated data that interlinks all of the CGIAR core research domains and that enhances the data-sharing culture at all centers and at all levels; these data assets accelerate research and form the basis of new alliances and innovations.
- CGIAR information security and data management practices are prioritized in both organizational policy and governance in support of the One CGIAR vision and implementation of the CGIAR 2030 Research and Innovation Strategy.
- CGIAR provides technical support to those public, private, and non-profit partners seeking to implement global data standards and leverage their data for developing new insights, data-driven capabilities, and services.
- CGIAR progressively builds well-curated data assets across key food-security research domains including genomics, crop improvement, large-scale agronomy, agroecology, environment, and socioeconomics that should become a critical enabler of CGIAR research and development interventions as well as those of its partners.

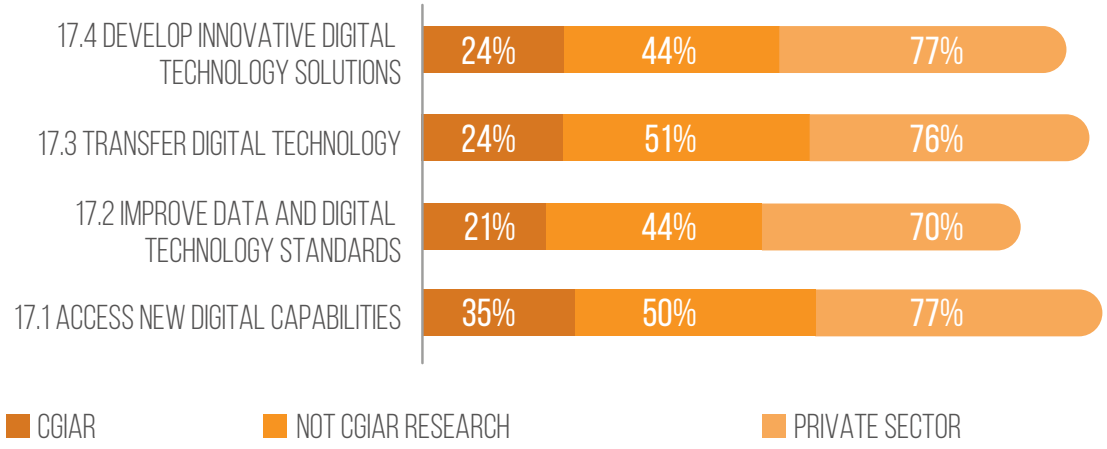
FOSTER DIGITAL ECOSYSTEM THINKING

THE CHALLENGE

Addressing the problems facing global food security demands complex approaches that require the involvement of a diverse, digitally-enabled ecosystem of actors and stakeholders. Accessing trusted and actionable data; aligning public, private, and non-profit investments; and finding and cultivating digital partnerships to effect positive change each present significant challenges. Building and managing strategic partnerships is critical for accelerating progress in digital agriculture, especially in developing and scaling the use of innovative digital products and services, the co-development of data and digital technology standards, and accessing digital capabilities. Digital platforms—technology-enabled, multi-sided networks that facilitate stakeholder interactions—have a central role to play in facilitating such partnerships. Digital platforms are also proving to be well-suited to help organizations stay abreast of rapid changes in their industries and markets.

CGIAR has the global partnerships, emergent data infrastructure, and domain expertise to become a trusted digital intermediary; to build collaborative communities around digital disciplines for agri-food research; and to develop, validate, or help scale the innovations that will be needed to achieve the SDGs. In this sense, a digital strategy for CGIAR must be a digital platform strategy—enabling the creation and operation of as many digital platforms as may be required to support collective actions needed for the transformation of food, land, and water systems—that informs how partnerships are pursued, shared services developed, policies created and enforced, and information infrastructure is built.

Figure 19. A majority of public, private, and non-profit survey respondents and interviewees noted the importance of building and managing strategic digital partnerships to access or develop new digital products, services, or capabilities and to improve overall standards development and coordination. CGIAR respondents tended to assess this digital partnership capability lower at their organization compared to the responses from other research organizations. Private sector respondents tended to view this capability as stronger in their organizations.



KEY INTERVENTIONS

To address this challenge, CGIAR must:

- **Develop CGIAR-wide digital alliances to enhance capacity and impact.** Digital technology partnerships are currently pursued at the center level or program level to meet specific research informatics needs (e.g., data storage and computation), or to develop new ways of engaging with stakeholders (e.g., moving data assets to cloud repositories where it is easier for stakeholders to co-develop solutions leveraging these data). One CGIAR presents an opportunity for CGIAR to foster organization-wide alliances that enable it to avert duplicate partnerships; negotiate with providers for commonly-used data or services (e.g., accessing commercial satellite imagery); access new digital capabilities via partnerships rather than making in-house investments; partner with digital product and service developers to extend the reach of CGIAR analytics on a regional or global scale (e.g., working with and through the mobile telephony and digital financial services industries); and speak with one global strategic voice on issues at the intersection of digital trends and global food security such as ethics, responsible collective action, and making the digital revolution as inclusive and impactful as possible.

- **Develop internal and external shared data and analytics services.** In the private sector, the most successful digital platform companies have prioritized the development of services that are both internal and external, creating a self-reinforcing dynamic that favors continual service improvements. When service providers are also users, they have a greater incentive to improve the services they are using and a greater ability to improve them for external use. CGIAR is well-equipped to begin developing such multifaceted digital alliances. The CGIAR OADM Policy is a good example: publishing pan-CGIAR standards-compliant data and data from its partners related to global challenges (e.g., climate adaptation) into open, cloud-based repositories facilitates data discovery and use beyond CGIAR and

enables the co-development of new analytic services with impact partners (e.g., mobile phone operators seeking to develop services supporting climate-smart agriculture). Such multifaceted services can facilitate pre-competitive collaboration and collective action across the array of public, private, and non-profit stakeholders needed to drive progress toward the SDGs.

- **Cultivate open digital CoPs** for operations and research innovation. CGIAR has multiple cross-cutting technical communities focused on key functional disciplines (e.g., Intellectual Property, IT Managers; Information and Data Management; Monitoring Evaluation and Learning; Communications; Partnerships) and specific digital-research disciplines (Ontologies, Crop Modeling, Socioeconomic Data, Geospatial Analysis, Livestock Data, Data-Driven Agronomy). With more than 5,000 members, these CoPs serve as a critical connection to wider communities in these disciplines and enable CGIAR researchers and employees to remain abreast of innovation and industry standards in their technical or functional disciplines and serve as a vetting and partnership development mechanism that can help not only CGIAR, but also assist the industry as a whole in overcoming its fragmentation. CGIAR must continue to foster these communities and build formal mechanisms for integrating internal and external experts into their governance.

> Some kind of marketplace for partnerships would make sense. Most of the time people pull back from [partnership] engagement because of cost and time, but if someone can play an active intermediation role, this might be a role for public interest actors... We can't have [the] private sector doing the convening. You guys can really be impactful through [undertaking] this convening and oversight role.
>
> An interviewee from an agriculture start-up

OUTCOME STATEMENTS

- CGIAR reduces the costs of research through development and co-design of digital services for its researchers, such as cloud storage, computational power, and access and use of proprietary data services.
- CGIAR co-develops precompetitive collaboration and collective action on data standards, digital products and services, and innovation across public, private, and non-profit actors needed to drive progress toward the SDGs.
- CGIAR experts collaborate with and actively build partner networks with wider technical and research communities on critical topics at the intersection of digital tools and technologies and the agricultural research for development sector.

MISSION-DRIVEN DIGITAL INNOVATION

CGIAR LEGACY AND CAPABILITIES

CGIAR research on scaling[103] indicates that innovations are often more able to reach scale as part of a package of technologies, policies, and partnerships. Digital innovations will be an increasingly important part of such packages in rapidly digitizing economies and societies. Intellectual property organizations worldwide note that innovation at the intersection of digital technology and the life sciences is accelerating. Registered digital inventions may be relevant anywhere along the spectrum of agricultural research for development from the early stages of scientific discovery through to newly released products and services. It is nearly impossible, however, to predict which nascent technologies will become disruptive,[104] and in what industries, until they have matured.[105]

Figure 20. Turning challenges into clear, targeted missions and launching defined projects with clear experimentation, learning, and feedback mechanisms could be a means of targeting mission-driven innovation to meet the SDGs.

Source: Mazzucato, M. (2018). Mission-Oriented Research & Innovation in the European Union (Rep.). doi:10.2777/360325

Mission-driven innovation processes have the potential to help organizations harness this inventive power,[106] yet there is no universally-applicable process to help them do so. The United States National Aeronautics and Space Agency (NASA) is emblematic of such mission-driven innovation. Research into how innovation is managed at NASA found that the organization applies the "stage-gating" or "phase-gating" process for classifying and managing the maturation and adoption of innovations. While these approaches have proven to be useful, they can also create an illusion that innovation management is a linear process. In the case of NASA, partnerships, strong collaborative networks, and external "shocks" such as a change in budget or policy

were observed to be the primary factors propelling an innovation toward further development and toward being used in a mission.[107] "Earth shots," such as meeting the SDGs, are arguably much more challenging to accomplish than the "Moon shots" of more than half a century ago because they require broad-based collective action to achieve their goals.[108] Like NASA, CGIAR consists of largely autonomous business units connected by a common mission. In the case of CGIAR, this has made structural reforms challenging to implement, but it has also contributed to the independence and ultimate impact of CGIAR science.[109]

Trusted public-interest organizations such as CGIAR can play critical roles in building the targeted, mission-driven innovation needed to achieve the SDGs:

- ***Knowledge brokers.*** Public-interest actors such as CGIAR can facilitate the exchange of validated data and evidence needed to develop a diverse stakeholder ecosystem that has an interest in sourcing and fostering innovation in a given domain.[110]
- ***Validators of innovation***. Novel innovations are disseminated and validated most effectively when they are examined in concert with existing, well-established knowledge.[111] CGIAR can claim such a role in validating and disseminating digital innovations.
- ***Facilitators of multi-stakeholder governance.*** Digital innovation implemented with the scale and agility that will be needed to achieve the SDGs will require "more decentralized and open-ended governance, which takes place in new places– markets, networks and partnerships, as well as conventional policy and politics."[112] CGIAR is well-suited to facilitating such governance.

In 2017, CGIAR launched a digital innovation process designed to source digital innovations linked to the research portfolio—the Inspire Challenge[113]—that embodies several of the features of a multi-stakeholder "innovation factory" for digital agriculture for development; this process has begun to attract new bilateral sources of funding. One CGIAR represents an opportunity for the organization to use its varied expertise and multi-stakeholder governance to make the novel connections needed to target, foster, and scale digital innovations for global food security. With the more cohesive and proactive "strategic posture" [114] made possible by One CGIAR, the organization can become the world's largest digital innovation lab for global food security.

DIGITAL STRATEGY IN THE TIME OF COVID-19

When the COVID-19 crisis subsides, the efforts to respond to it may well be seen as a triumph of agile, global, collaborative science. The rapid mobilization of governments, non-profits, research organizations and industry to align research and development efforts for therapeutics, vaccines, and diagnostics is unprecedented. This was made possible by global multi-stakeholder data sharing such as the COVID-19 Open Research Dataset, a public repository of tens of thousands of scientific studies, and well-developed biomedical ontologies. Data standards and data sharing opened the way for scientists to apply massive computing power to model and identify promising compounds for treatment in days—a process that could have taken years in the laboratory.

These capabilities are the future of agricultural research for development. Wide-ranging CGIAR digital strategy research interviews conducted in 2020 showed dramatic, rapid shifts in digital culture and practice in public, private, and non-profit food security organizations:

- **Organizational digital shifts:** Rapid shift to online/remote working and rapid organizational shifts. New buy-in by leadership. New appreciation for IT departments that managed the rapid transition to digital.
- **Digital streamlining of methods in research:** Acceleration in the use of machine learning to augment human labor (e.g., seed sorting).
- **Increased demand for well-described data:** COVID has accentuated the need for interoperable, interpretable data broadly related to food (e.g., access, value chains, harvest).
- **Increased demand for computation:** Computational research is validated alongside observational and experimental research.
- **Rapid shift to remote agricultural advisory services**

In a few short months, the sector become dramatically more digital, and many interviewees thought that these shifts were here to stay. The COVID-19 crisis demonstrated that mission-driven global "Earth shots" are achievable through digitally-enabled innovation and global collective action.

KEY INTERVENTIONS

To claim the full opportunity of digital innovation strategy and management for global food security, CGIAR must:

- **Strive to source the most impactful digital innovations across the research-to-delivery spectrum.** It is nearly impossible to predict which innovations will be transformational as they mature. In order to manage this complexity, CGIAR's digital innovations will be developed in close alignment with national and regional agricultural development strategies, sourcing digital innovations that target specific agricultural research-for-development challenges. CGIAR must source, foster, evaluate, and accelerate an array of innovation types spanning the spectrum of scientific discovery and delivery in order to target innovation to the specific challenges needing to be solved. [115]

- **Engage partners in prioritization and culling digital innovations.** CGIAR is implementing a more unified process for prioritizing and culling innovations (called "stage-gating") in light of these innovations' potential contributions to the SDGs. CGIAR must test hypotheses for these innovations, monitor their development progress, and change course as needed. Partnerships linked to a wider industry ecosystem are fundamental to making innovation management processes such as stage-gating successful.[116] CGIAR must incorporate wide-ranging stakeholder consultation and engagement to source digital innovations, guide them to proof of concept, and design these efforts from the outset such that these tools and technologies can reach large-scale dissemination and adoption.

- **Develop a global digital innovation practice with regional dimensions.** Through implementation of the digital intervention areas of data, AI, digital services, and digitally-enabled trust and collective action across all CGIAR Research Action Areas and internally strengthening its digital foundations in leadership and governance, data management and use, information infrastructure, digital skills, and digital partnerships, CGIAR can build an overarching, global organizational capability for digital innovation strategy and management that equips it to engage national, regional, and global partners with a more unified voice and deliver concrete digital contributions to help meet global goals. Regional initiatives, programs, and digital technology and service offerings--guided by multi-stakeholder governance--can accelerate the application of responsible digital innovation in service of the SDGs.

THEORY OF CHANGE

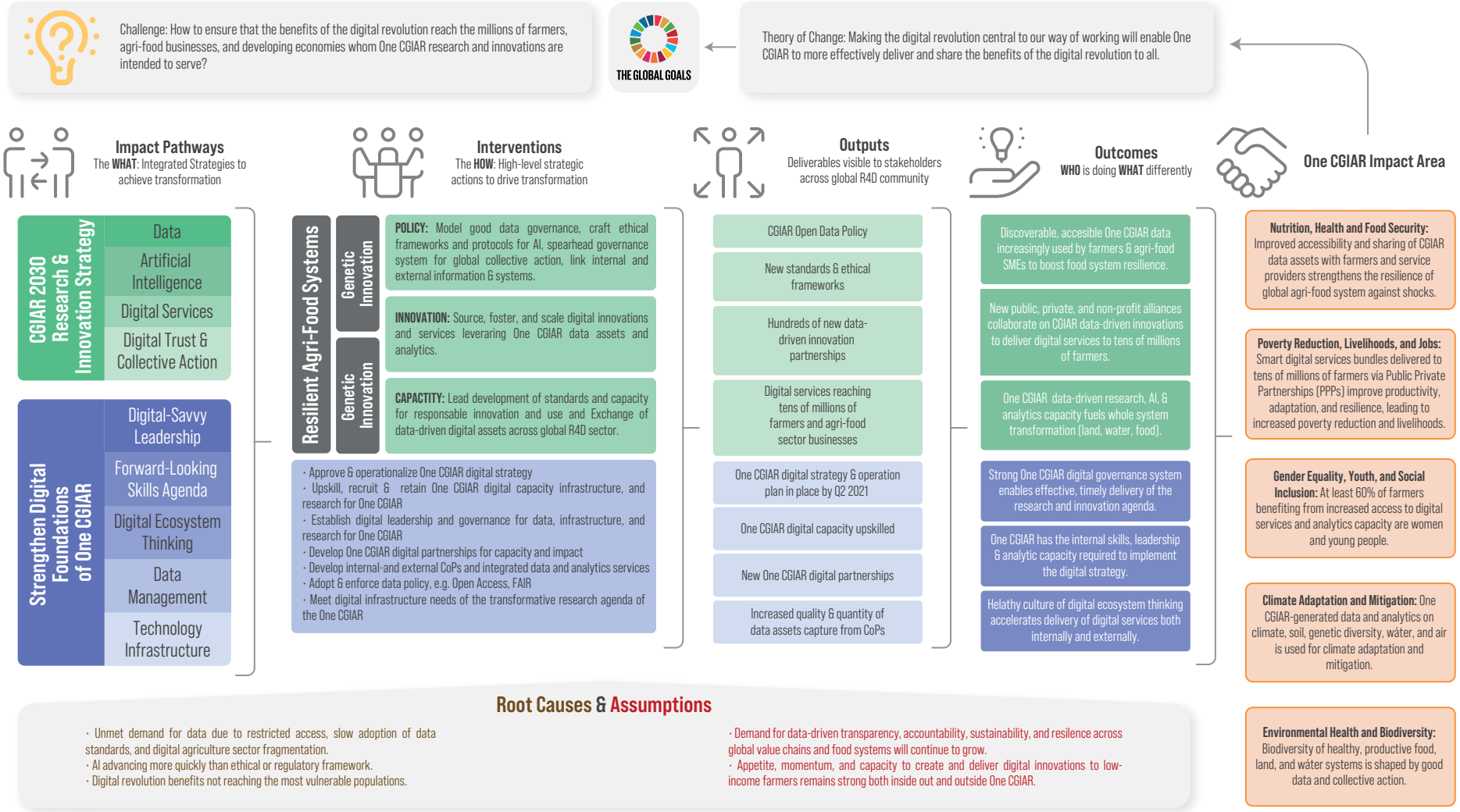


Figure 21. A high-level theory of change for the digital One CGIAR: through harnessing four digital trends poised to transform the economy and society while building its own digital capabilities, CGIAR must more effectively deliver impact across all its impact areas and expand the reach of the benefits of the digital revolution.

Source: CGIAR digital strategy research

MATURITY OF CROSS-CUTTING DIGITAL CAPABILITIES

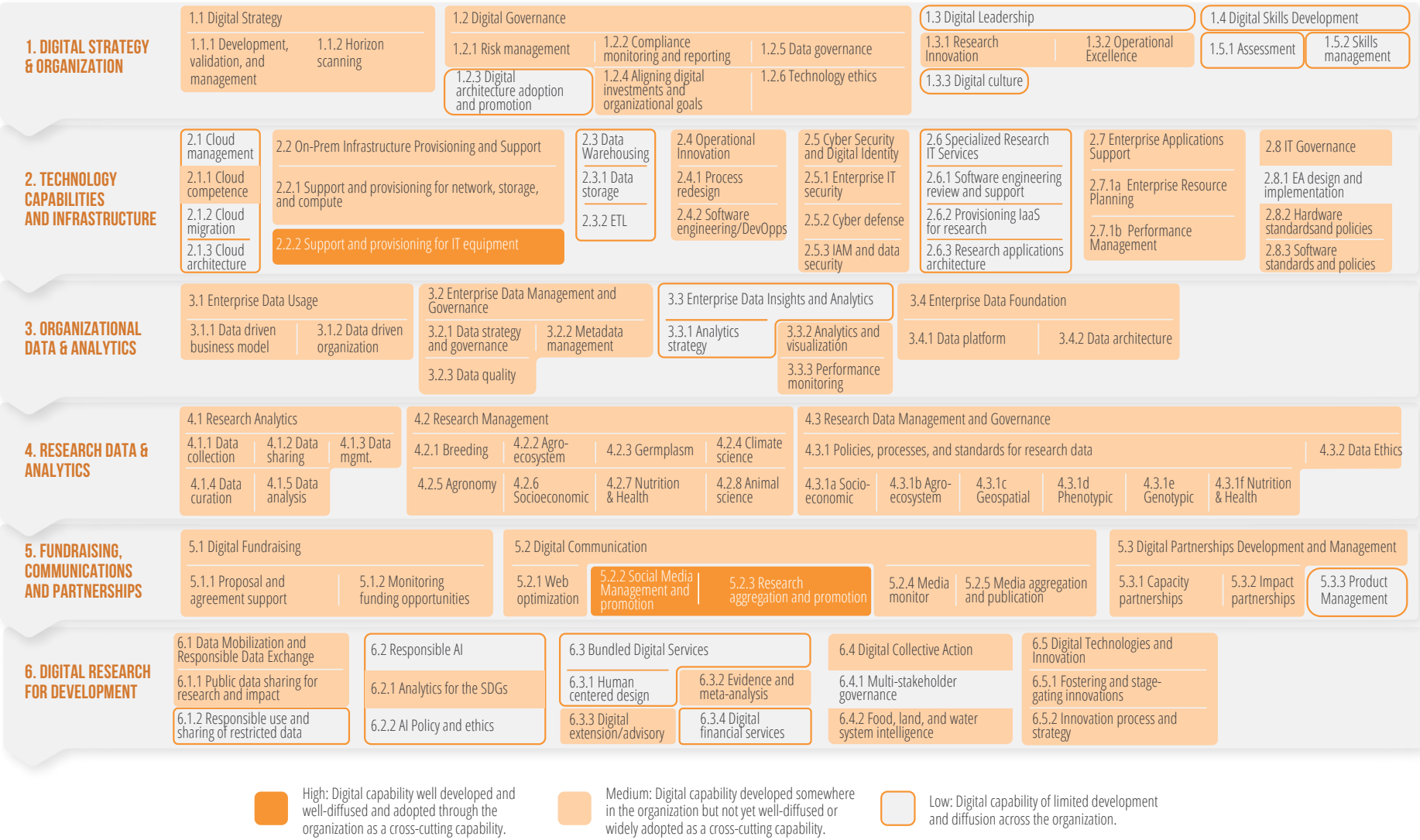


Figure 22. A high-level digital capability model of One CGIAR noting how well digital capabilities in research, operations, and overall organizational functions are developed and diffused across the organization. "Medium maturity" indicates that a particular capability is developed somewhere in the organization, but remains poorly diffused or siloed.

Source: CGIAR digital strategy research.

ANNEXES

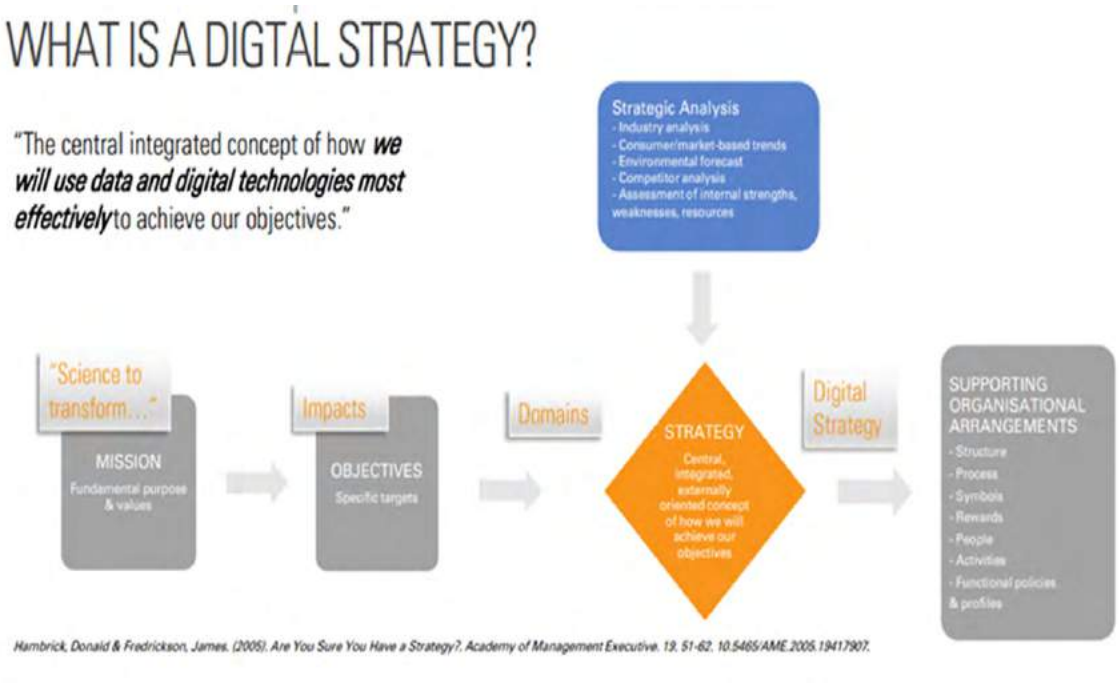
ANNEX 1: WHAT IS A DIGITAL STRATEGY?

It might be helpful to define what a digital strategy is and discuss where it fits into a larger organizational strategy, specifically how it applies to One CGIAR. Organizational strategy has been defined as the "central integrated, externally oriented concept for how an organization will achieve its goals". The role of a digital strategy is to describe in detail how data and digital tools will enable an organization to achieve these goals. Similar to an organizational strategy, a digital strategy is based on and supports the organization's mission, objectives, and areas of activity or domains. It is both part of the integrated concept for how the organization will act in the world and part of the organizational capabilities needed to execute that concept.

A digital strategy should:

- Guide the organization to most effectively use its data and digital tools in service of its purpose;
- Be informed by strategic analyses through observing larger sector trends and the internal capabilities and resources of the organization; and
- Inform the development of those digital systems within the organization (e.g., structure, systems, recruiting practices) needed to execute its strategy.

Figure 23. Placing digital strategy within the context of an organizational strategy, the wider industry context, and supporting organizational arrangements.



Source: Adapted from Hambrick, D., & Fredrickson, J. (2005). Are you sure you have a strategy? Academy of Management Perspectives, 19(4).

Similar to an organizational strategy, a digital strategy must be informed by strategic research and analysis: looking at wider trends, querying other actors in the sector, and assessing internal strengths, weaknesses, and capabilities. CGIAR conducted wide-ranging strategic research and analysis to answer three key questions:

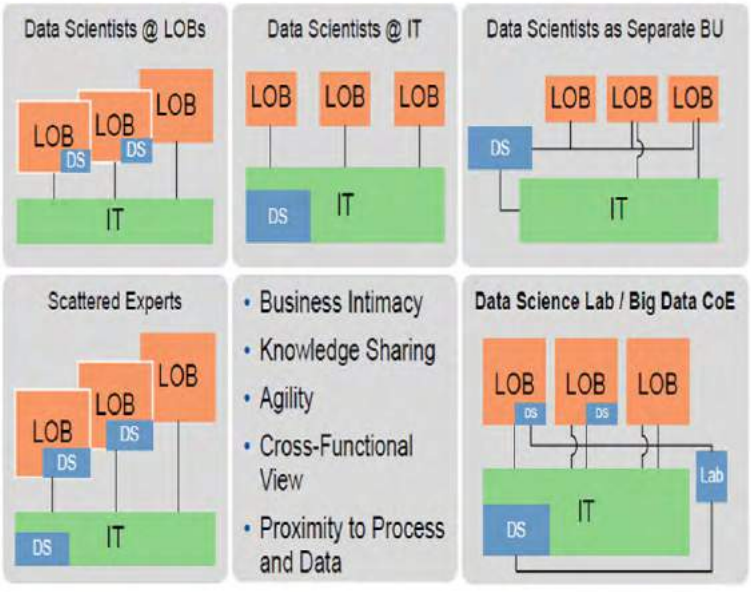
- What digital trends have the potential to transform agricultural research for development in the next 10 years?
- What should CGIAR do to effectively navigate or leverage these trends?
- What roles should public-interest actors such as CGIAR play in digital agriculture?

ANNEX 2: DIGITAL INNOVATION IN THE ONE CGIAR STRUCTURE

Those entities that have adopted digital strategies closely linked with their organizational strategy are significantly better prepared to navigate digital disruption in their sectors. For CGIAR, the function of a digital strategy will be to guide the alignment of digital efforts across the organization to build a more unified digital vision.

The "Digital Services" function described under the One CGIAR Institutional Strategy and Systems Division begins to address the overarching shared services, common standards, clearer IT vision, and governance needed to help equip CGIAR to become a more cohesive, digitally-enabled organization. It will be tasked with building a more unified approach to IT service management (ITSM) and systems across the organization. ITSM is an established good practice for beginning to rationalize, harmonize, and measure the quality of IT services. It is commonly implemented by creating a catalog of approved services an IT department will support. While there are many advantages of this practice in terms of cost-savings, developing common standards, and creating an increased ability to measure service quality, it can sometimes be a disincentive for the development of new capabilities or innovations—which, by definition, would not be in a service catalog.

Figure 24. Creating a "Center of Excellence" or "Lab" structure that is linked to, but separate from, IT is a common way organizations seek to build data science capabilities. This structure would be well-suited to supporting the array of domain-specific applications of data science in food security research.

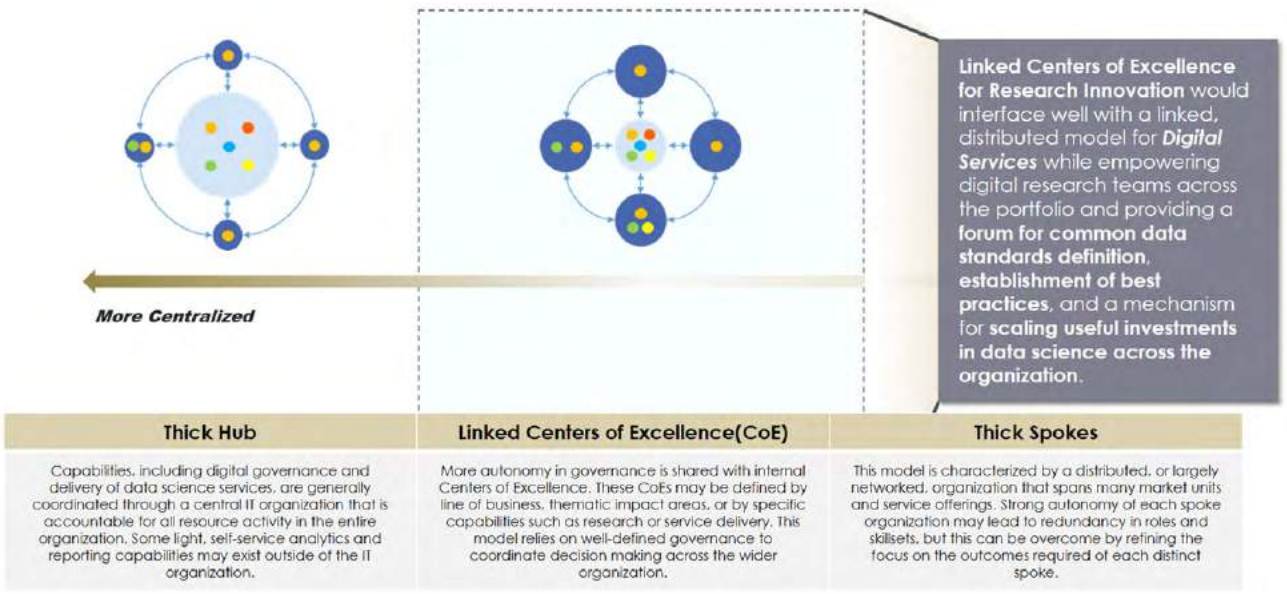


Source: Linden, A., Herschel, G., Chandler, N., & Parenteau, J. (2013, September 4). Organizational Principles for Placing Advanced Analytics and Data Science Teams (Rep. No. G00255555). Retrieved August 15, 2020. from Gartner website: https://www.gartner.com/doc/258421

The One CGIAR 2030 Research and Innovation Strategy places data science and digital innovation functions within research areas known as Science Groups. This evolving organizational structure would include a Digital Services Unit that provides IT services to research areas. Some organizational research points to the strengths of creating a "lab" or "center of excellence" linked to, but separate from, IT services. Such a unit

supports the development of data science capabilities by separate lines of business and integrates them with the rest of the organization. This approach appears to be well-suited to the research needs of One CGIAR and to supporting the array very domain-specific applications of data science in research. It would also serve an integrative and scaling function across the organization.

Figure 25. The One CGIAR vision aligns well with a "Linked Centers of Excellence" model for IT and digital governance.



Source: CGIAR digital strategy research.

ANNEX 3: STUDY DESIGN

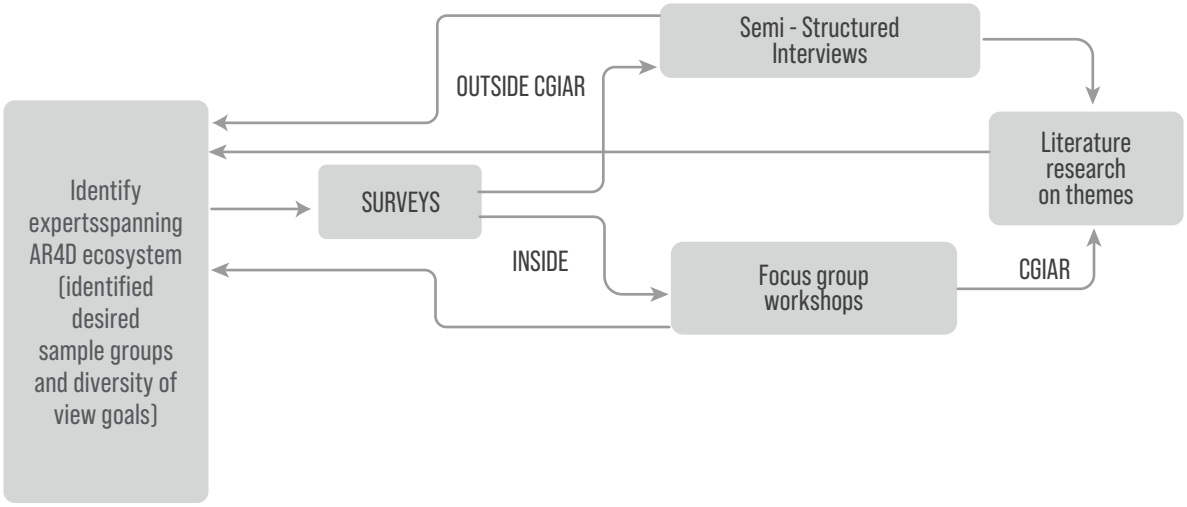
In 2020, CGIAR conducted wide-ranging consultations and internal assessments to better understand how trends in the access to and use of digital technologies may affect global food security, the roles public-interest organizations should play in leveraging and shaping these trends, and the capabilities One CGIAR must cultivate to fully leverage digital technology in the service of the agile, adaptive ***transformation of food, land, and water systems in a climate crisis***. This consisted of 165 surveys, 80 semi-structured interviews, 10 internal workshops on digital trends and capabilities, and an extensive literature review. Aiming for a gender balance in the sample, 83 respondents across the different research groups were female. They represented 38% of the entire sample.

Through these efforts, CGIAR sought to understand the key capabilities and enablers of successful digital organizations in general; the status of digitization in the agricultural research-for-development ecosystem in particular; and key priority actions for CGIAR to make the digital revolution "central to its way of working."

FREQUENCY AND DESCRIPTIVE STATISTICS OF SURVEYS

The 165 surveys, conducted in the second half of 2020, were completed by a wide range of people across CGIAR and the wider agricultural research-for-development ecosystem. More than 60 CGIAR researchers and others from the 15 centers participated. The rest of the survey sample included external stakeholders in the sectors of non-CGIAR research, development funding and finance, private sector (not consulting), private sector (consulting), and small-scale and start-up organizations in the agri-food industry.

Figure 26. High-level workflow for data gathering



HIGH-LEVEL WORKFLOW FOR DATA GATHERING (SEE FIGURE 26):

1. An initial list of potential interviewees was assembled, working through the Big Data Management Team, Big Data Platform Steering Committee, International Advisory Board, and CoPs (with some 5,000 members).
2. Potential respondents were contacted about participating in the digital strategy process (either through a focus group or a semi-structured interview), and all respondents who expressed an interest in participating were sent the same digital survey, that included some questions solely for CGIAR respondents.
3. CGIAR respondents were scheduled to participate in internal focus groups on key technical or functional areas in the organization. Participants would be anonymous and "Chatham House Rules" would be observed (no individual comments will be ascribed to anyone).
4. Semi-structured interviews were scheduled with external experts (also noting that no individual comments will be ascribed to any person).
5. Both groups (focus groups and interviewees) were asked to suggest other experts in their networks that might have unique perspectives on the One CGIAR digital strategy. Themes arising from the focus groups and interviews were explored more through literature research; this informed areas in which the process might benefit from having one or more diverse expert views.

The process continued until the minimum desired sample group numbers were achieved and there was diversity in the group (geography, gender, discipline, role in the industry).

The process was reviewed and approved by the Institutional Review Board of the International Center for Tropical Agriculture before the study launch. The survey was administered via Google Form. The first page included information on informed consent (including the purpose of the study, how data would be managed and protected, what risks there might be of participating, and clarifying that participants could withdraw from the study at any time). In order to continue the survey, participants agreed to the informed consent information. After answering questions about their organization and their professional role, the survey moved on to questions about the development of digital technologies, the digital agriculture landscape, and how effectively their organization leverages the key enablers of successful digital organizations.

Various frequency and descriptive statistics from the survey results have been reported in the main text of the digital strategy report. These are summarized in Annex 4.

THEMATIC ANALYSES OF MORE THAN 80 SEMI-STRUCTURED INTERVIEWS

More in-depth interviews were conducted with respondents from outside CGIAR on digital trends and the organizational capabilities needed to navigate them. This included individuals in agribusiness, food companies, development funding and finance organizations, large IT firms, consultancies, life sciences organizations, start-ups, and farmers' groups (see Annex 5).

INTERNAL FOCUS GROUP WORKSHOPS

Ten workshops were conducted with internal CGIAR groups. Focus groups representing cross-cutting technical (e.g., crop modeling) or functional (e.g., communications) disciplines across CGIAR identified priority initiatives, investments, and the digital capabilities needed to be able to fully leverage digital technologies in support of their discipline.

Workshop participants also completed the digital survey, but CGIAR respondents had three additional questions: where they work in the CGIAR organization; what key functions or capabilities they routinely deliver; and the key functions or capabilities on which they depend. This served as an important source for the rapid assessment of key digital capabilities for a digital One CGIAR.

LITERATURE RESEARCH

Interviews and workshop findings were complemented with a review of sector development strategies, research publications, and futures analyses to identify the digital trends affecting agricultural research for development and key areas in which public-interest actors such as CGIAR can help shape and leverage these trends to contribute to global food-security goals. The themes of this literature research were guided by the internal workshops, interviews, and the digital survey responses.

ANNEX 4: THEMATIC ANALYSIS OF SEMI-STRUCTURED INTERVIEWS

Q1. What two or three digital technology trends have the potential to transform agriculture over the next 10 years?

Responses to this question clustered into four broad digital trends: ***transformational technologies, digital business models, data and analytics, and rapid global expansion of digital services.*** (See Figure 27.)

Transformational technologies were specific technologies that respondents saw as disrupting agriculture businesses and practices in some way, particularly AI and sensor technologies.

Among **digital business models**, multi-sided markets mediated by digital technology (also known as digital platforms) were mentioned explicitly as a positive and potentially transformational disruptor, alongside two types of digital services that would also lend themselves to being platforms. In combination with other technologies, these platforms are becoming more localized and fit for purpose for agriculture, creating opportunities for service personalization on a large scale.

Data and analytics was noted by nearly a third of respondents as potentially driving significant change, such as through new analytic methods and a massive growth in available data, the increasing timeliness of available data thanks to expanding digital technologies, and emerging consensus about the importance of data standards and interoperability.

These three trends were seen as being propelled by the **rapid global expansion of digital services**, which is quickly enabling farmers to be more digitally-savvy, affecting virtually all aspects of economy and society, and that **the combination of these trends** can be particularly powerful.

Figure 27. Distribution of interviewee responses to the question *"What two or three digital technology trends could transform agriculture over the next 10 years?"*

Transformational technologies	**81**
AI	23
Proximal sensors (including IoT)	22
Remote sensing	18
Blockchain	10
Apps	3
Cloud/edge computing	3
Robotics	2
Video conferencing	2
Digital business models	**59**
Digital platforms/multi-sided markets	42
Digital financial services	11
Digital advisory services	6
Data & Analytics	**48**
Advances in analytics	13
More available data	13
Interoperability & standardization	12
Other mentions of data	7
Real-time data	3
Rapid global expansion of digital services	**21**
Mutually reinforcing impact of two or more of the trends	**8**

Barriers to leveraging the trends

A number of barriers were mentioned by respondents. Data services can still be too expensive to be used by a large number of rural customers. There is a dearth of granular, good-quality data on agriculture to support the development of targeted digital agricultural services. Several respondents noted that access to basic

digital technology in rural areas is still quite low and costly, and, until the economics of serving customers in these regions makes sense, this is unlikely to change. Several respondents were also concerned that growing and unresolved concerns about data privacy and ownership still exist.

Q2. What can public-interest actors such as CGIAR do to foster the more effective use of digital technologies in the agricultural sector?

Three major themes can be gleaned from interviewees' responses.

Develop the digital ecosystem. Nearly 40 percent of respondents stated that CGIAR and other public-good organizations need to take a whole-of-sector view in developing digital agriculture. This could take several forms, such as through building more market or sector intelligence, providing public-good data, evaluating the evidence of impact, and promoting good practice.

Improve access, standards, and responsible practices for data. Public interest actors can facilitate access to data, establish data standards, and promote good practices in data stewardship and management.

Convene and collaborate. Less than a fifth of respondents noted that public-interest organizations such as CGIAR can play a catalytic role in facilitating industry-wide collaboration, convening multiple food system actors and helping to identify areas for pre-competitive collaboration on resolving bottleneck issues.

Q3. What do you think an organization can do to take advantage of these trends to more effectively achieve their objectives?

Three major themes emerged from the respondents' replies:

Tend to data access, management, and sharing. Over a third of respondents noted the importance of improving at least one aspect of the overall data value chain from collection, transmission, storage, analysis, and re-use. Several respondents noted that the adoption of common data standards across their organization and the sector will be important for meeting an increased demand for data in the sector through improving data discoverability and interoperability. Most of these respondents noted the importance of identifying and leveraging an organization's comparative advantage in contributing to a larger data ecosystem rather than trying to go it alone.

Increase digital technology skills. More than one-third of respondents noted the importance of building digital technology skills either in their organizations or in the wider ecosystem, or both. Partnerships were seen as a key mechanism for building more awareness and accelerating adoption of digital skills in the wider ecosystem, whereas within organizations these skills could be developed through training or recruitment of new personnel.

One respondent noted that developing digital skills needs to be part of an organization's overall strategy if it is to remain relevant in the sector, and that filling this skills gap is a matter of urgency. Several respondents noted the particular importance of establishing partnerships for meaningfully using AI: AI skills can be difficult and costly to source, and these skills must be paired with deep agriculture domain knowledge to be applied meaningfully in agriculture. As a result, even those very digitally-savvy organizations that can afford AI talent seek to form partnerships to find the agricultural domain expertise needed in order to design and apply relevant AI systems.

Partner to accelerate progress. About one-quarter of respondents addressed the role of partnerships as a means of filling digital technology skills shortages, increasing data access, and helping advance data interoperability. Some respondents noted the importance of engaging the private sector, including suppliers

and retailers, as a means of accelerating overall digitization in the sector, and said that a more digital sector should create opportunities to reach a wider number of small agri-food businesses. It was noted that digital agriculture partnerships may require new collaboration models since these alliances can be difficult and time-consuming to find, form, and evaluate.

Q4. What role do you think industry-wide collaboration can play to foster the more effective use of digital technologies in agriculture?

Four common themes emerged among respondents about the role of industry-wide collaboration in digital agriculture. It can:

- Help fill capability and data gaps;
- Establish new or strengthen existing standards;
- Foster new collaborations to accelerate development of the industry; and
- Enable specific collaborations.

FILL CAPABILITY AND DATA GAPS

Slightly less than half of the respondents noted that creating effective partnerships will be critical for them to fill gaps in their organization's data, skills, and domain knowledge.

i. **Data**
   Respondents noted that data-sharing partnerships can help fill gaps in fragmented data sets, establish some functional standards or standard operating procedures, and begin to meet the increasing demand from modelers of crops, ecologies, and economies. One respondent noted that technical collaboration is required to establish some granularity standards for data to be useful for particular types of research or modeling. Several other respondents noted that there are still pervasive gaps in available, reliable farm-level national agricultural data, and that these can only be addressed through collaboration and partnership among governmental entities, researchers, and the private sector.

   One respondent noted that the incentives for data sharing and use could be strengthened, such as through placing a value on specific data (e.g., through explicit linkages to particular revenue or cost-saving opportunities), and that getting this right could be a driver of digital transformation within the sector as a whole.

ii. **Skills**
   Echoing some responses in Q2, a few respondents noted that partnerships or industry collaboration could help guide overall efforts in helping broker skill-sharing or aggregating and meeting the demand for services.

iii. **Sector intelligence**
   Respondents noted a whole-of-sector view can be built through establishing partnerships. The benefits of adopting this approach would include building a better understanding of different actors in the data value chain and avoiding the unnecessary duplication of investments through greater exposure to what others in the sector are doing.

ESTABLISH AND STRENGTHEN STANDARDS

About one-quarter of respondents identified partnerships as critical to establishing or strengthening digital standards for agriculture. These might include the development of or support for data interoperability standards, standardizing technical approaches, advancing data protection and privacy standards, and facilitating data sharing.

COLLABORATIONS TO STRENGTHEN THE REACH AND IMPACT OF DIGITAL AGRICULTURE

Roughly a third of respondents noted that broad-based industry collaboration can expand the reach and impact of agricultural research through linking it with new digital products or services; developing publicly-available reference architectures to increase and normalize the use of digital technologies (such as IoT and remote sensing) and research methods in the sector. Several respondents pointed to a need to build and apply overall sector intelligence about what digital products and services exist, what their market access is, who likely investors and consumers would be, and where opportunities may lie to bundle digital services in the agricultural sector. Applied sector intelligence of this type was seen as important for driving down the cost of digital innovation in agriculture, guiding public and private investment, and catalyzing new (and new types of) partnerships.

ANNEX 5: SURVEY RESULTS

The research team conducted 165 surveys in the second half of 2020. It received responses from a wide range of people across CGIAR and the wider agricultural research-for-development ecosystem. This included 60 CGIAR respondents from the 15 centers and the System Office. The remainder of the survey sample included external stakeholders in the sectors of non-CGIAR research, development funding and finance, private sector (not consulting), private sector (consulting), and small-scale and start-up organizations in the agri-food industry. Respondents answered questions about digital trends, the status or health of key enablers and capabilities in their organizations, and their connections with the wider digital ecosystem for agriculture.

Frequency and Descriptive Statistics of the Survey

The following descriptive information was captured in questions 1 through 11 of the survey:

FIGURE 28. SURVEY RESPONDENT ORGANIZATION TYPE.

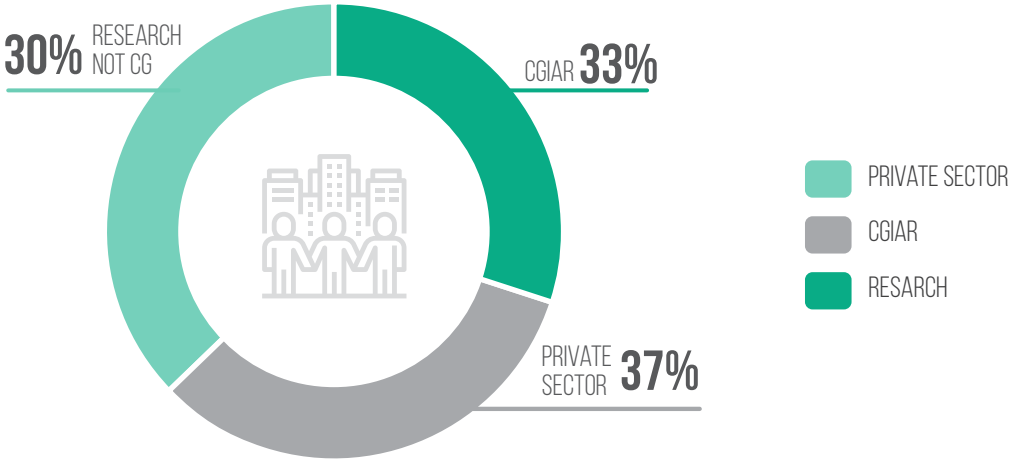


FIGURE 29. PRIVATE SECTOR SURVEY RESPONDENT ORGANIZATION TYPE.

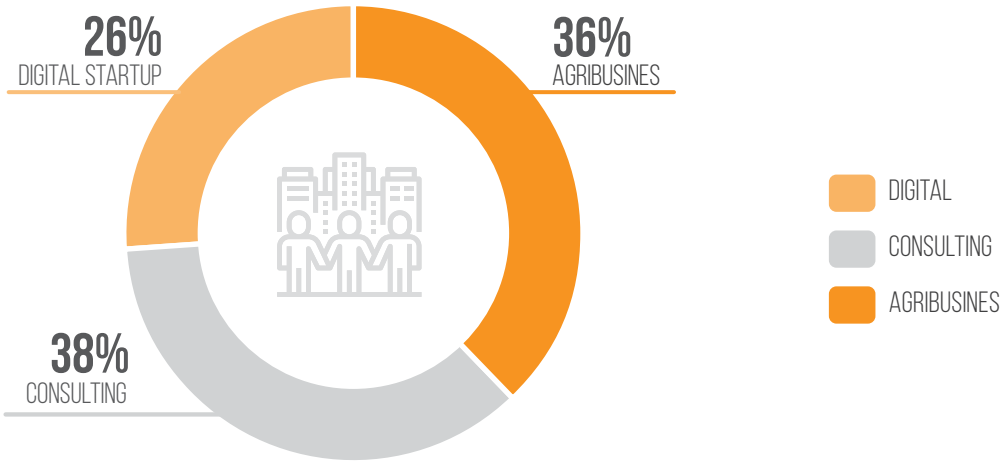


FIGURE 30. NON-CGIAR RESEARCH ORGANIZATION RESPONDENTS' ORGANIZATION TYPE.

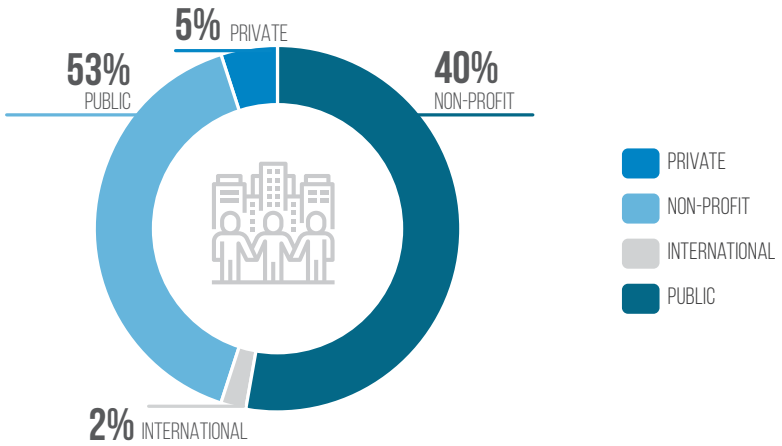


FIGURE 31. SURVEY RESPONDENTS BY REGION.

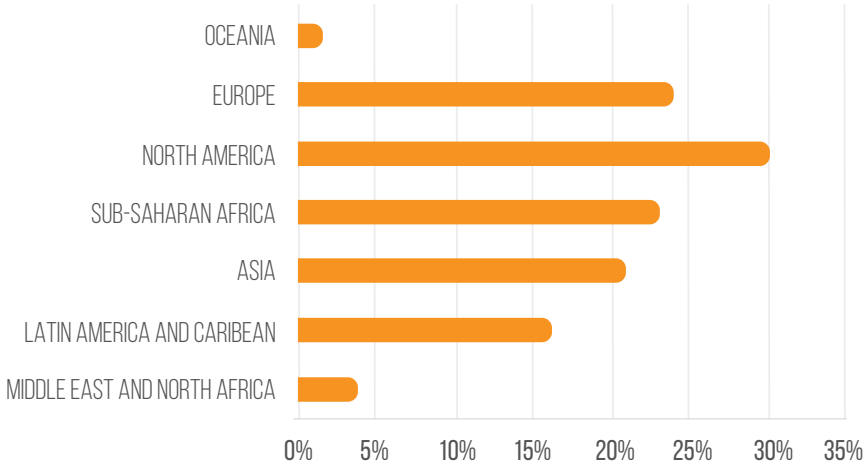
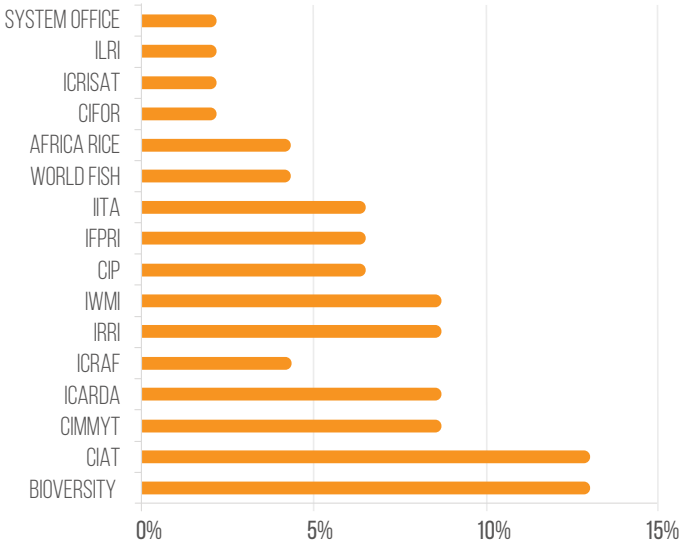


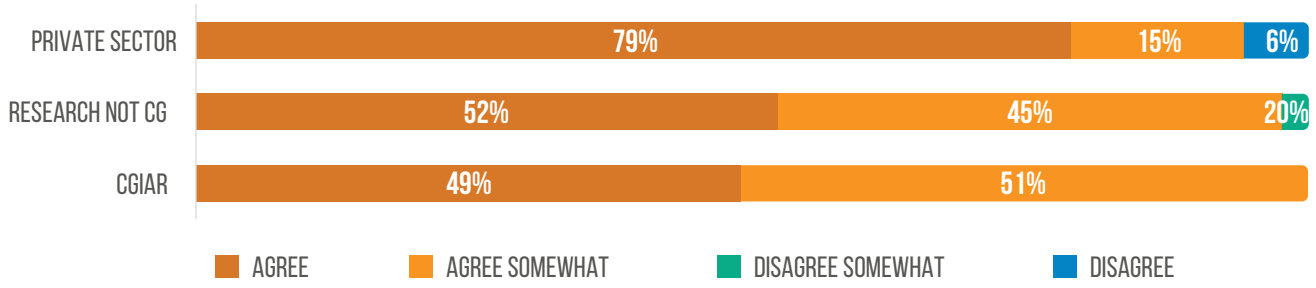
FIGURE 32. SURVEY RESPONSES BY CGIAR CENTER OR BUSINESS UNIT.



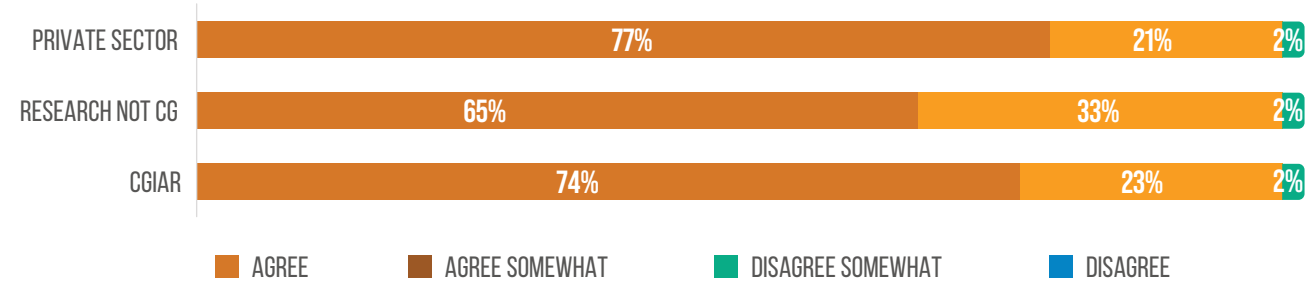
Survey responses regarding digital trends and the effectiveness of the organization in being able to leverage them (questions 12-21)

1. Q12

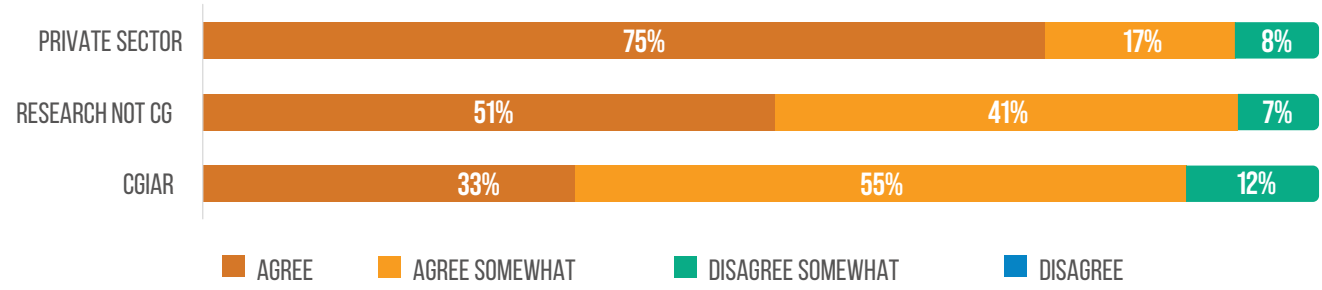
12.1 To what extent do you agree that the agricultural sector is changing rapidly due to widening use of digital technologies?



12.2 To what extent do you agree that life sciences research is changing rapidly due to widening use of digital technologies?

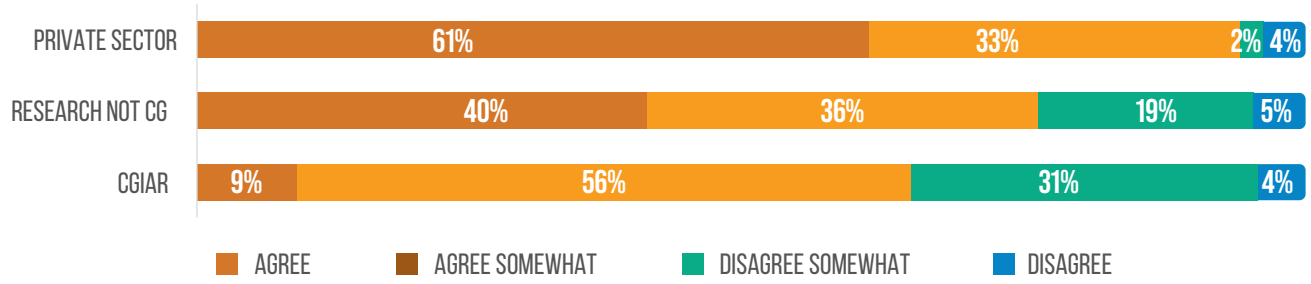


12.3 To what extent do you agree with the following: My organization collaborates effectively with other organizations on issues of common interest related to the effective use of digital technologies?

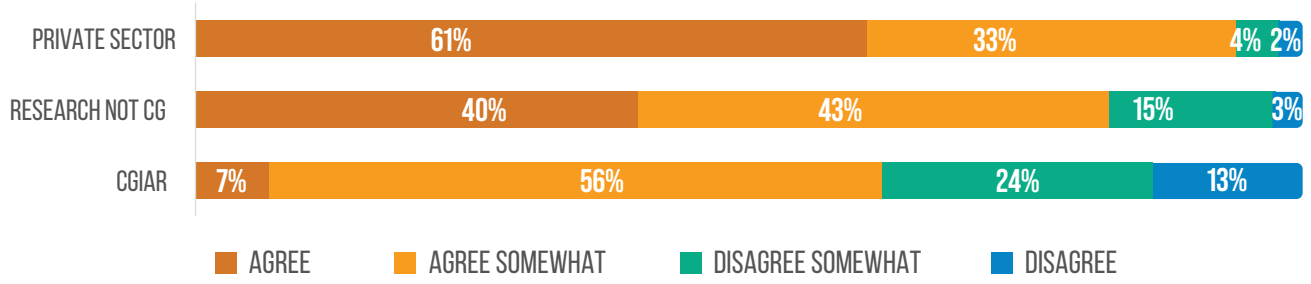


2. Q13

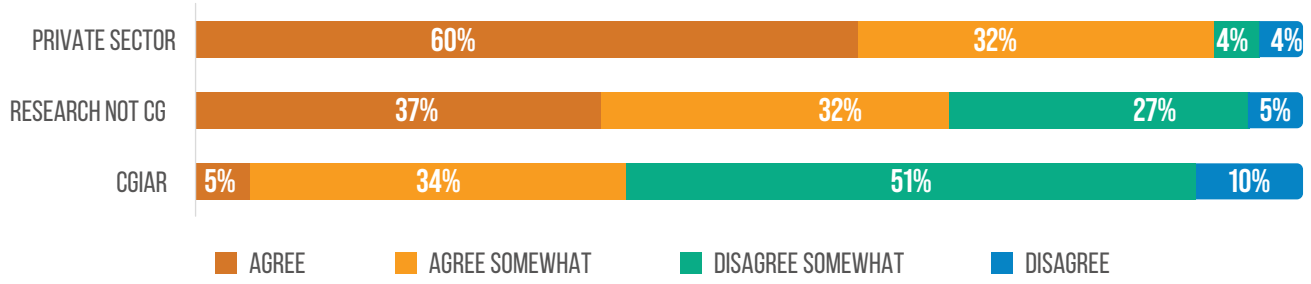
13.1 To what extent do you agree that your organization promotes effective use of data and digital technology through a clear strategy to leverage digital technologies?



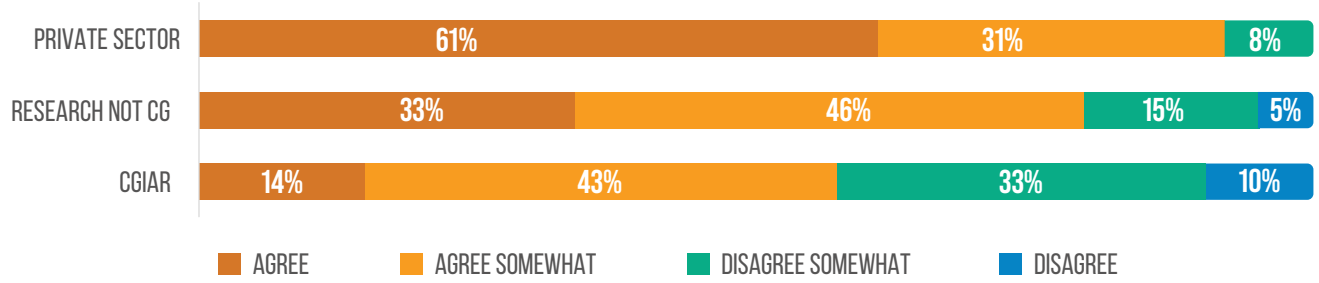
13.2 To what extent do you agree that your organization promotes effective use of data and digital technology through agovernance, policy, or management directives that enable digital innovation?



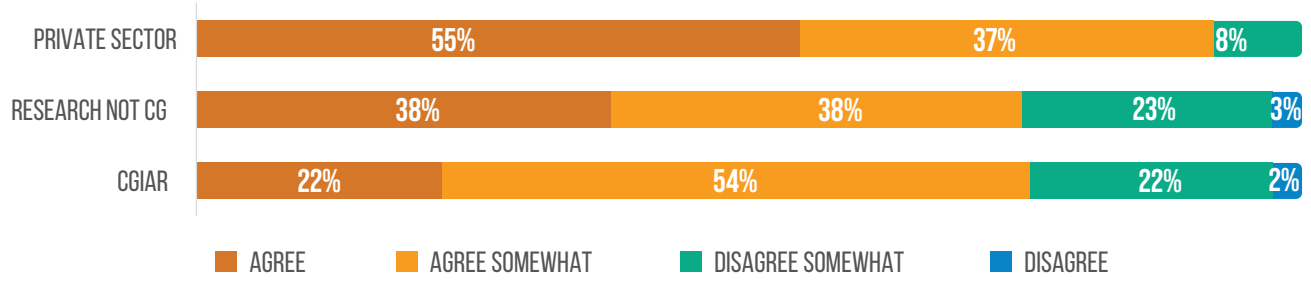
13.3 To what extent do you agree that your organization promotes effective use of data and digital technology through: a clear framework to prioritize digital technology investments?



13.4 To what extent do you agree that your organization promotes effective use of data and digital technology through: [enabling internal capabilities e.g. IT, Finance, HR, Legal?

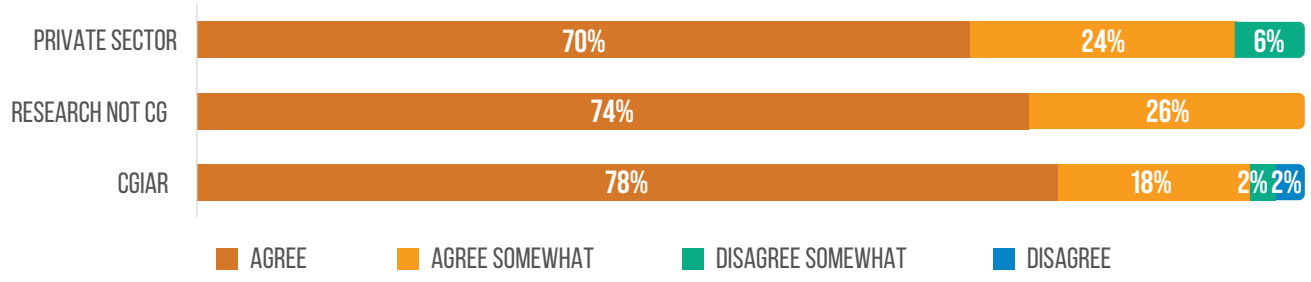


13.5 To what extent do you agree that your organization promotes effective use of data and digital technology through external engagement capabilities such as product management, communications, stakeholder engagement?

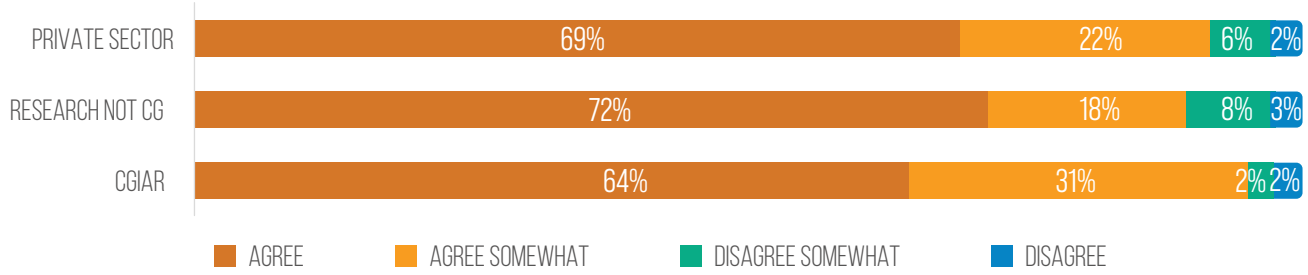


3. Q14

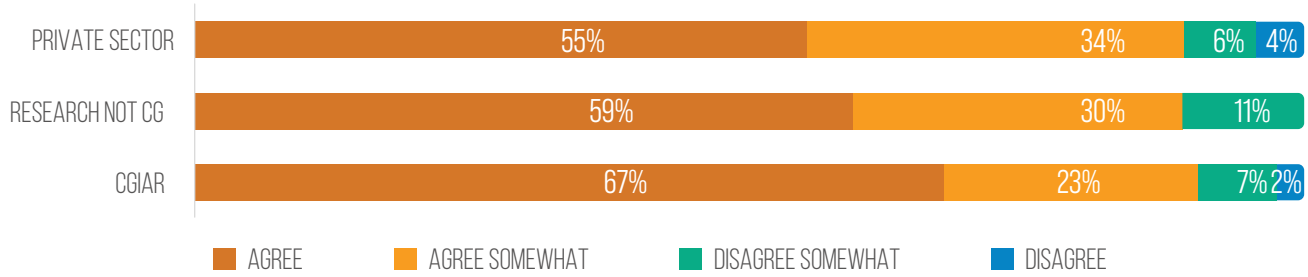
14.1 If my organization had a clear strategy to leverage digital technologies it would help me make better use of digital data technology to achieve my work objectives.



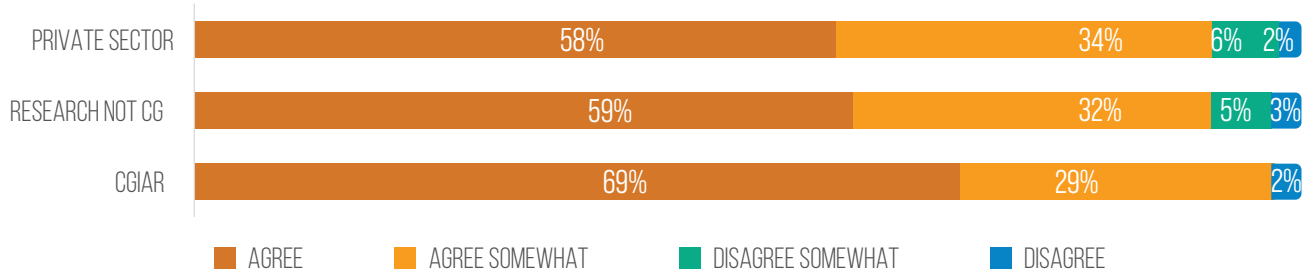
14.2 If my organization had more explicit governance, policy, or management directives enabling digital innovation it would help me make better use of digital data technology to achieve my work objectives.



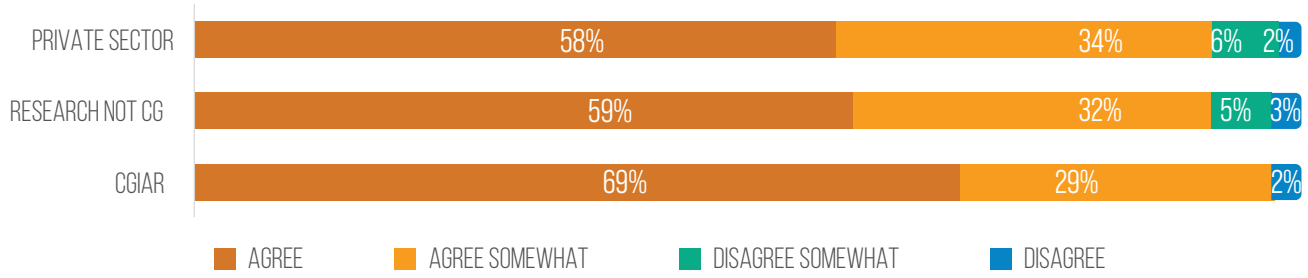
14.3 If my organization had clear prioritization of digital technology investments it would help me make better use of digital data technology to achieve my work objectives.



14.4 If my organization had stronger enabling internal capabilities (e.g. IT, Finance, HR, Legal), it would help me make better use of digital data technology to achieve my work objectives.

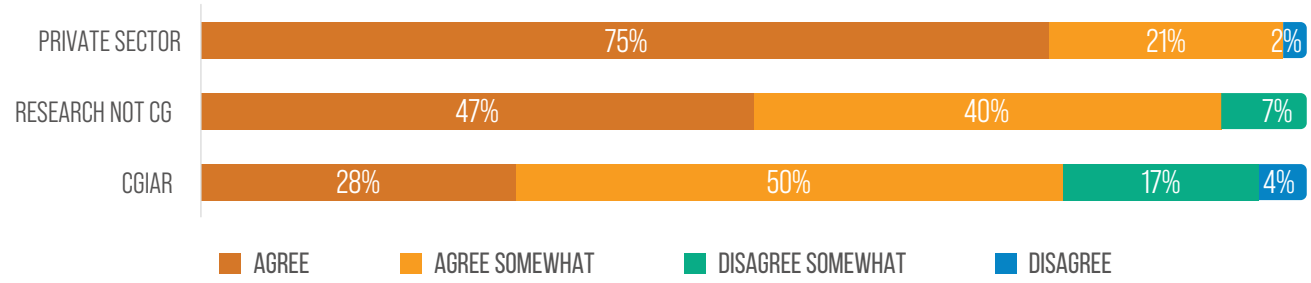


14.5 If my organization had stronger external engagement capabilities (e.g. product management, communications, stakeholder engagement), it would help me make better use of digital data technology to achieve my work objectives.

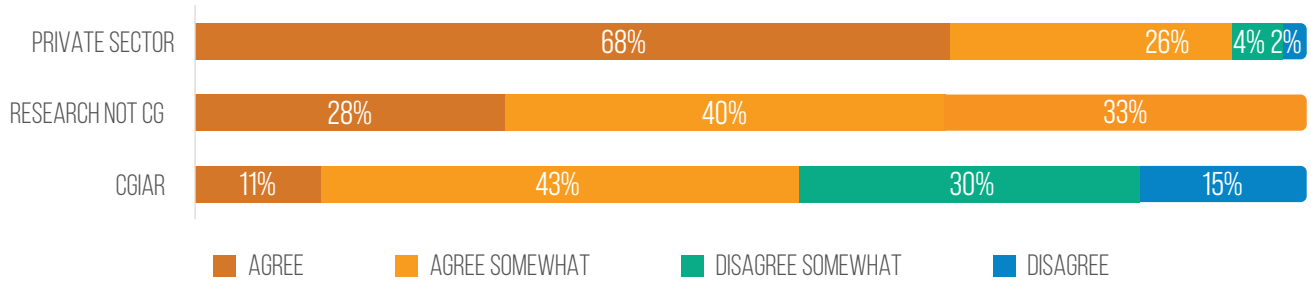


4. Q15

15.1 My organization enables staff to build digital capabilities.

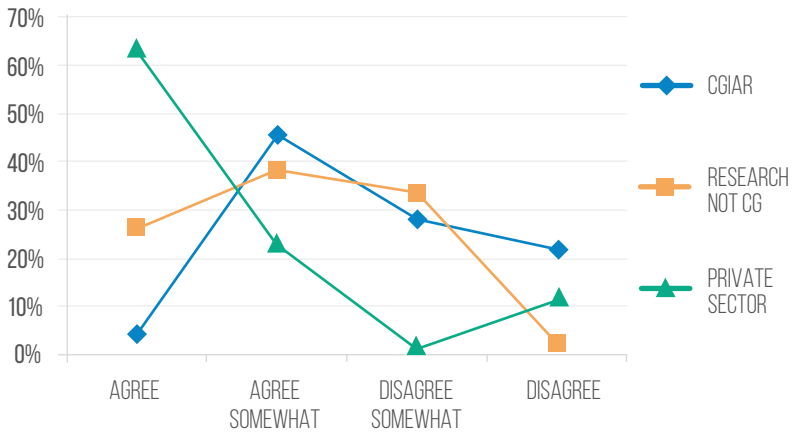


15.2 Leadership in my organization communicates clearly about our digital strategy and how it relates to operations.

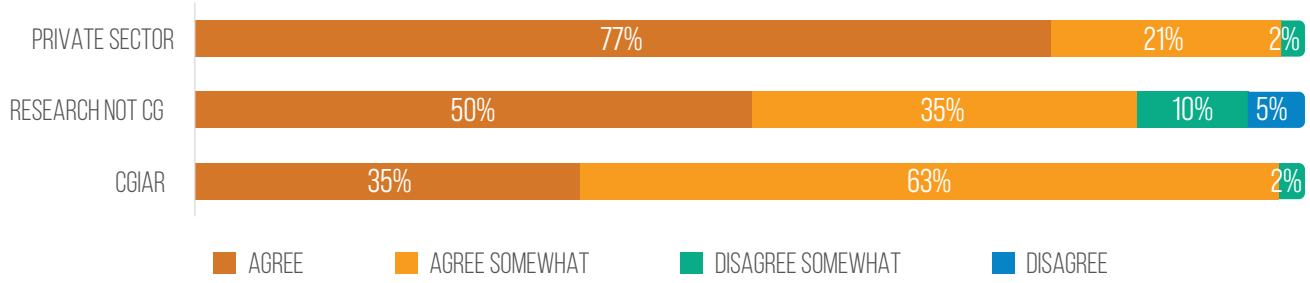


5. Q16

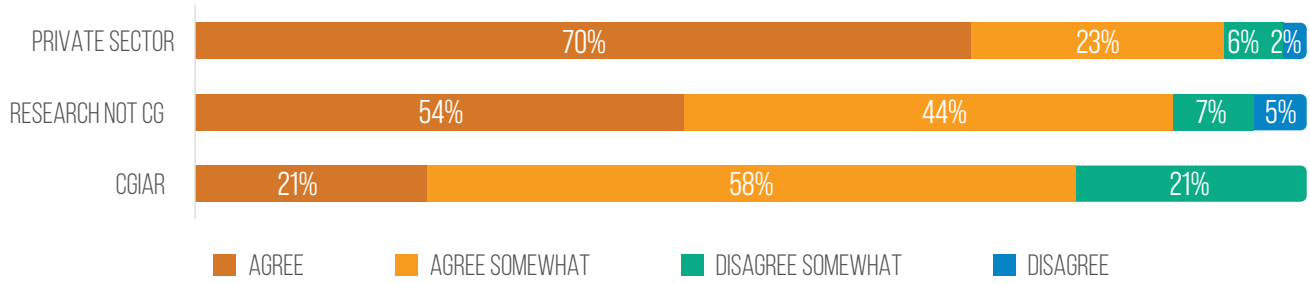
16. My organization as a whole has a clear agenda to develop digital skill.



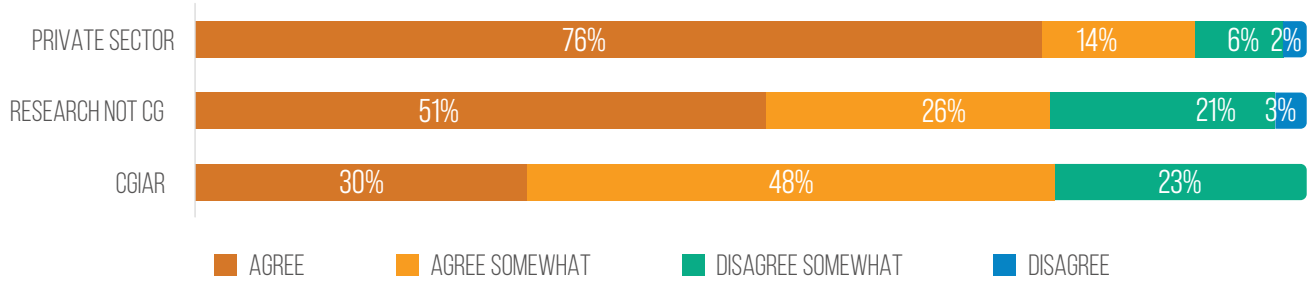
17.1 To what extent do you agree with the following: My organization partners or collaborates with other organizations to access new digital capabilities.



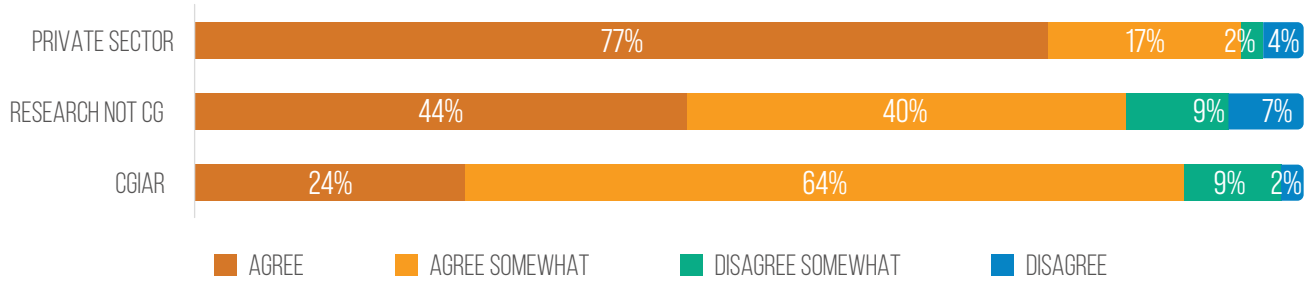
17.2 To what extent do you agree with the statement: my organization partners or collaborates with other organizations to improve data and digital technology standards.



17.3 To what extent do you agree with the statement: My organization partners or collaborates with other organizations to transfer digital technology.

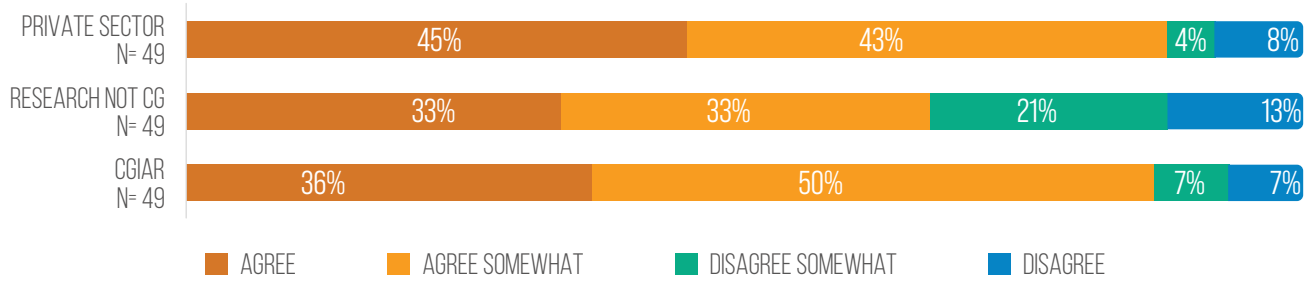


17.4 To what extent do you agree with the statement: My organization partners or collaborates with other organizations to develop innovative digital technology solutions.

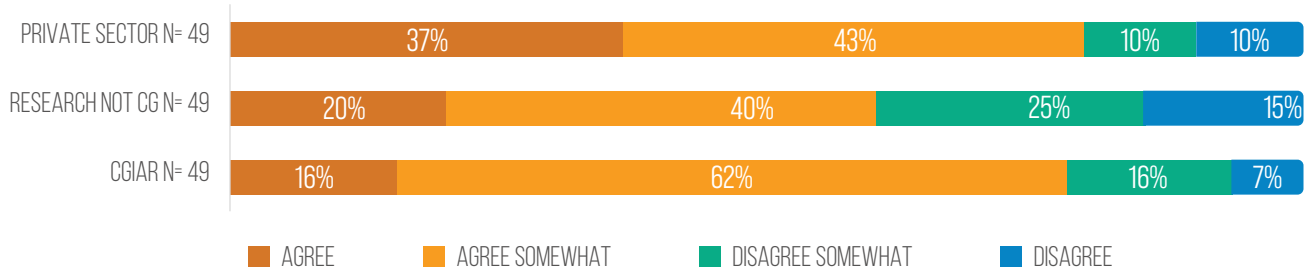


7. Q18

18.1 My organization has a unified view and policy on data sharing, access, and management.

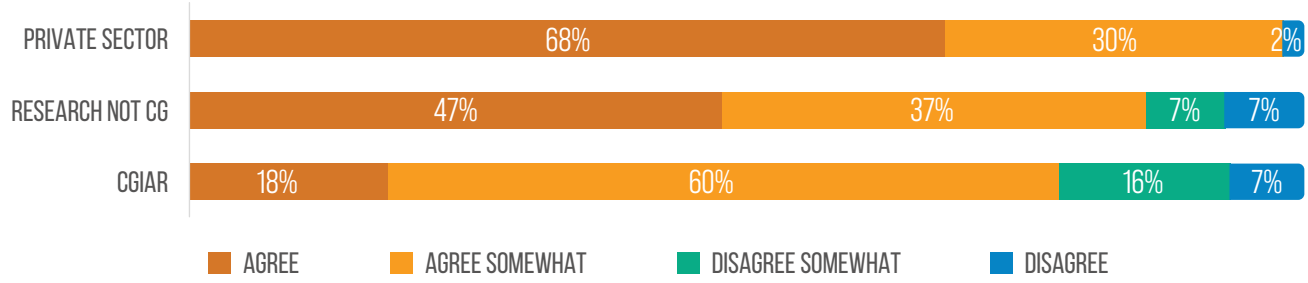


18.2 My organization's data are findable, accessible, interoperable, and reusable (FAIR).

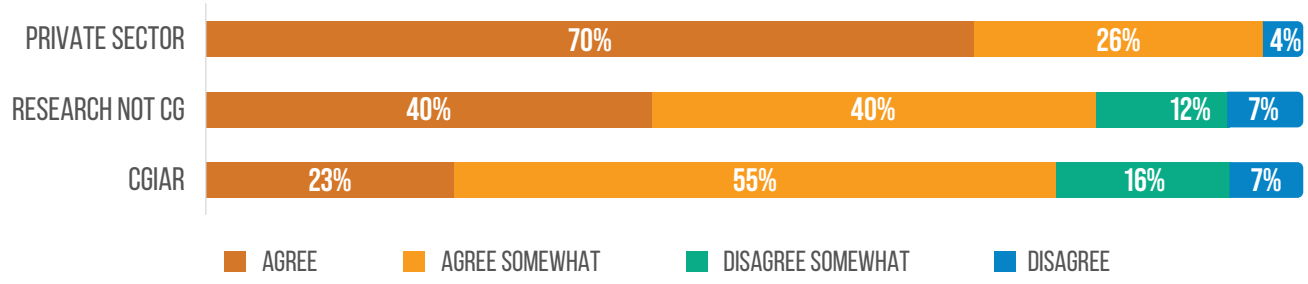


8. Q19

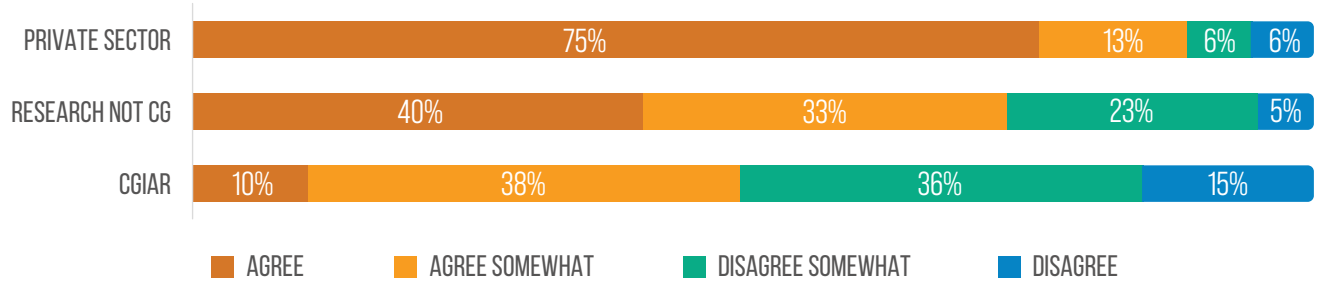
19.1 To what extent do you agree with the following statement: My organization's digital infrastructure enables me to do my work effectively.



19.2 To what extent do you agree with the following statement: My organization's digital infrastructure supports the use of new digital technologies.

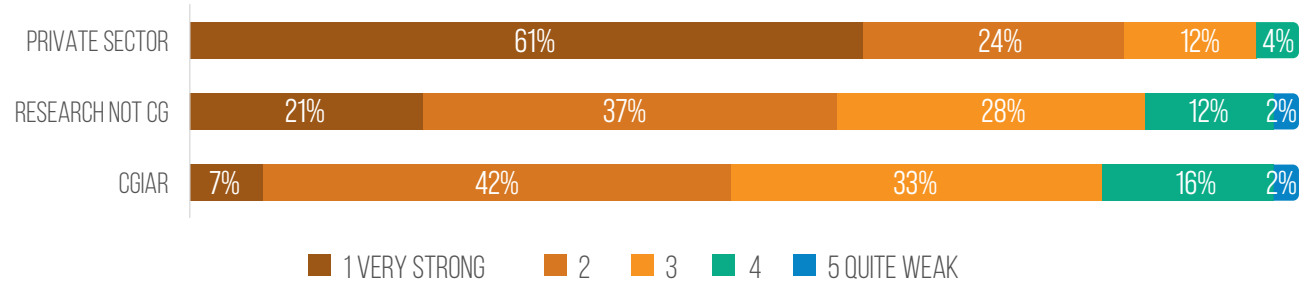


19.3 To what extent do you agree with this statement: Digital infrastructure is a priority investment for my organization.

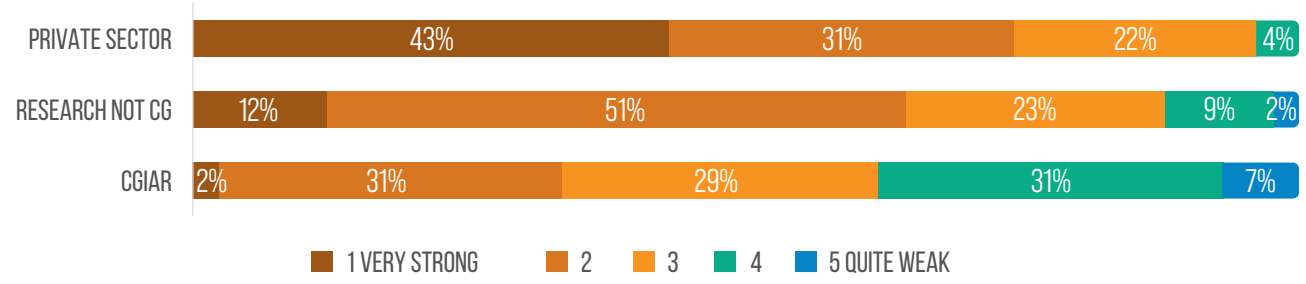


9. Q20

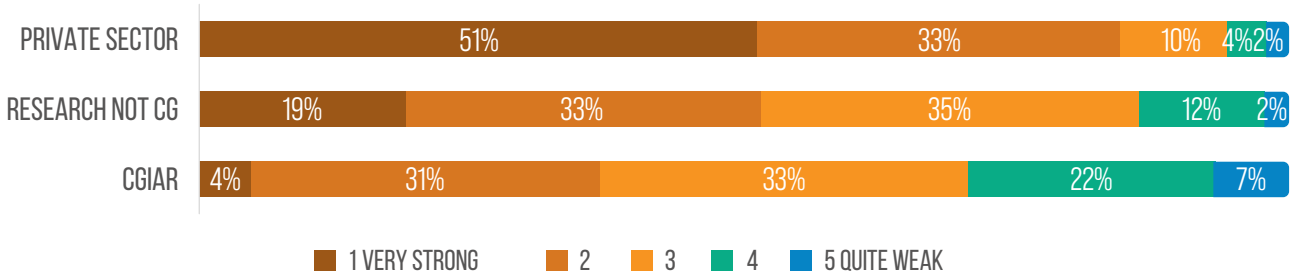
20.1 Rate the strength of digital leadership in your organization.



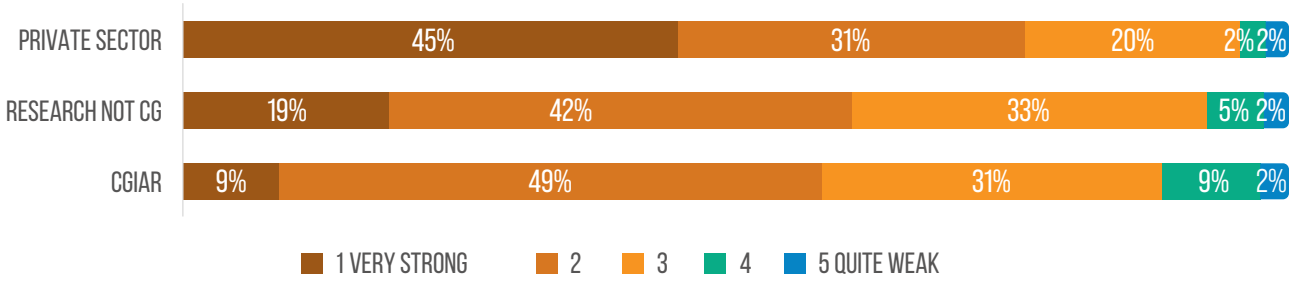
20.2 Rate the strength of digital skills development agenda in your organization.



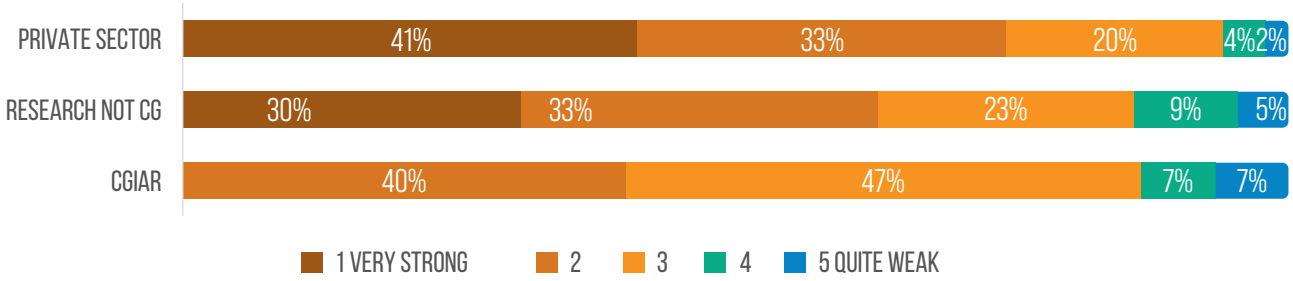
20.3 Rate the strength of digital ecosystem thinking in your organization.



20.4 Rate the strength of data access and management in your organization.

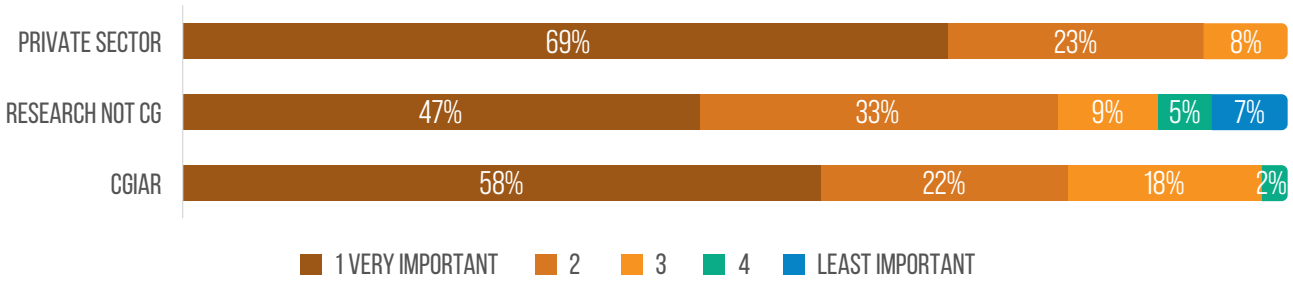


20.5 Rate the strength of your organization's digital technology infrastructure.

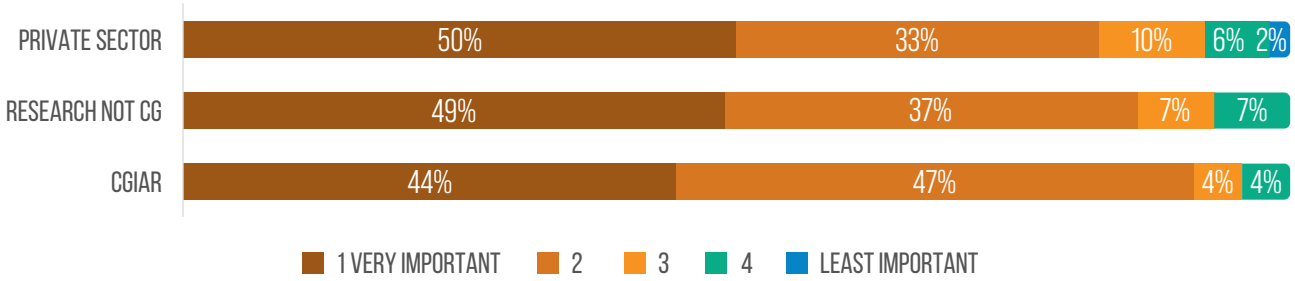


10. Q21

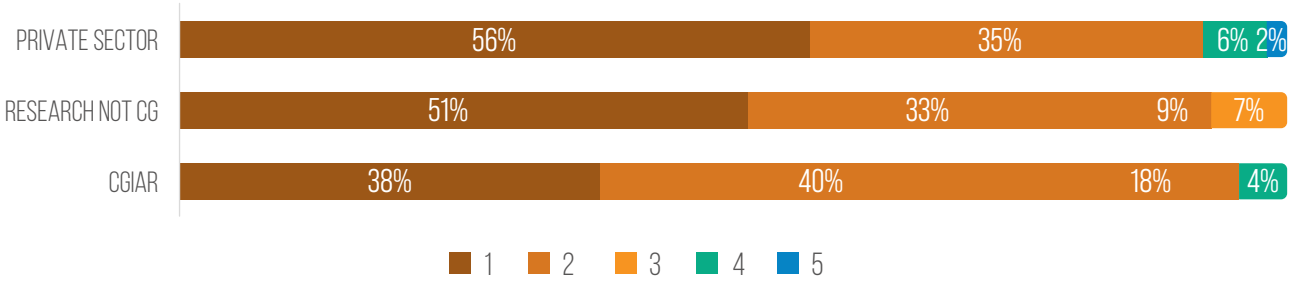
21.1 How important is digital leadership in your organization?



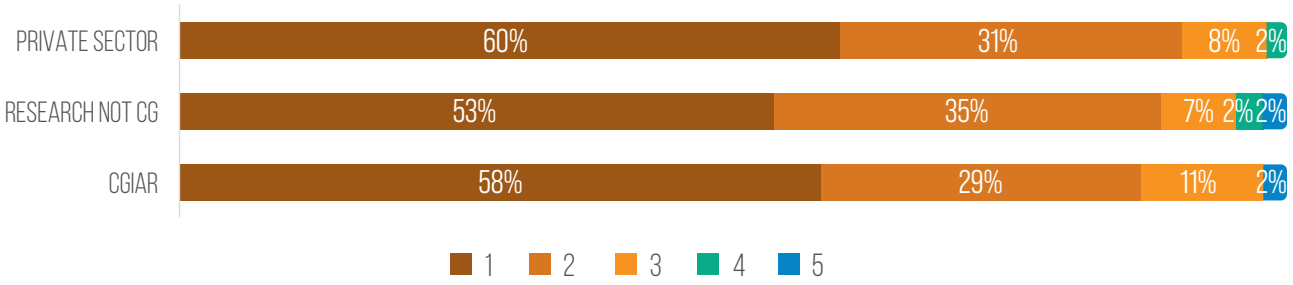
21.2 How important is having a digital skills development agenda for you to achieve your work objectives?



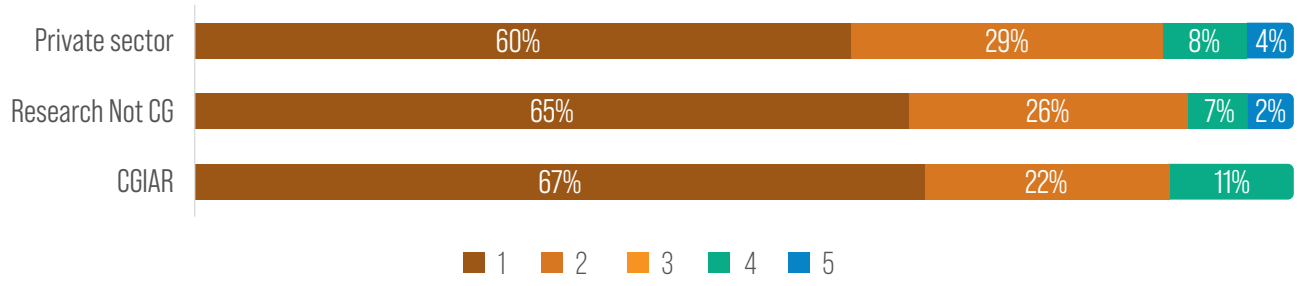
21.3 How important is digital ecosystem thinking for you to achieve your work objectives?



21.4 How important is data access and management for you to achieve your work objectives?



21.5 How important is digital technology infrastructure for you to achieve your work objectives?



ANNEX 6: RISKS OF ACTION OR INACTION

DIGITAL INTERVENTIONS IN RESEARCH		ACTION	NO ACTION
		DATA	
Type of risk	**Strategic / Reputational risk**	• Research becomes automated, less collaborative, and more extractive with our partners and stakeholders.	• Insufficient attention paid to breaking down silos and consolidating good practices can lead to balkanization and missed opportunities to collaborate and build capabilities.
		• Poor data sharing with private sector partners can become overly complex and may undermine CGIAR's mission of producing and delivering international public goods in agricultural research.	• Data silos continue or are reinforced, resulting in missed opportunities for research engagement and quality, which undermines a culture of data sharing.
	Operations risk	• Increased use of digital tools without close attention to the data feeding them can result in poor quality output or services.	• Lower-quality research products because of limited ground-truthing data.
	Technology risk		• Not capturing all key data, because of limited digital capabilities.
	Financial risk		• A shift of funding if data management is not increased.
			• Data redundancy and risk of expensive data collection.
	Regulatory / ethical risks		• CGIAR data assets unusable with inefficient data management, which prevents the data from being an asset for the organization and the sector.
		AI	
Type of risk	**Strategic / Reputational risk**	• AI projects implemented without a holistic view of their potential impact in food, land, and water systems may exacerbate harm on some part of the system.	• Underdeveloped skills and experience can lead to erroneous conclusions and the formulation of bad policy. • AI continues to be a strategic "blind spot" for CGIAR, inhibiting its ability to guide the responsible use of this technology. • Decreasing the relevance of CGIAR if it does not engage with digital technologies shaping the future of food security research and impact.
		• Over-optimism about what big data and algorithmic methods can deliver.	

DIGITAL INTERVENTIONS IN RESEARCH		ACTION	NO ACTION
		AI	
Type of risk	Operational risk	• Researchers become consumed with the technology and tools and pay more attention to them compared to research hypotheses and questions.	• Stagnation in the development of new methods. • Decreased ability to attract top tech talent.
		• Existing staff becomes alienated.	• Inefficiency and not being able to speak the same language.
	Technology risk	• Overreliance on complex tools that are difficult to use in real life, produces poor quality and/or not fit-for-purpose tools with low end-user uptake.	• Missing the rapid shift in the digital ways of working. (This is particularly noticeable in crises such as the COVID pandemic.)
	Financial risk		• Wasting resources due to lack of knowledge.
	Regulatory / ethical risks		• Degrading model capacity in the CGIAR can erode trust in the organization. • Low AI capacity in the organization erodes the ability of CGIAR to avert or mitigate the potential harms of AI when applied to social groups or ecosystems.
		DIGITAL SERVICES	
Type of risk	Strategic / Reputational risk	• Developing digital services that cannot be adequately scaled.	• Missed opportunity to cost-effectively reach millions of beneficiaries.
	Operations risk	• A proliferation of technologies and services can become a burden for researchers who may become overwhelmed unless some standardization is developed.	• Missing opportunities to leverage improved digital capabilities due to postponed investment(s).
		• Constant cybersecurity threats.	• Constant cybersecurity threats.
	Technology risk	• Choosing digital technologies or platforms for CGIAR communications that are not fit-for-purpose and will therefore not be used or will be ineffective.	
	Financial risk	• Increased demand for costly technologies and services that may not be affordable (e.g., proprietary imagery can be extremely expensive).	• Using outdated technology that needs to be treated as sunk costs.
		• Vendor lock-in when using commercial services.	
	Regulatory / ethical risks	• Increased compliance demands related to privacy or sensitive data.	• Information systems not reaching the target audience.

DIGITAL INTERVENTIONS IN RESEARCH		ACTION	NO ACTION
		DIGITAL TRUST AND COLLECTIVE ACTION	
Type of risk	**Strategic / Reputational risk**	• Increased use of digital technologies and tools may lead to increased visibility, if not properly handled, CGIAR's position on sensitive issues such as data assets related to genetic resources or genetic engineering could be misinterpreted. • Visualizations underlying research are not neutral. Without the proper expertise, there is the risk of losing sight of the underlying research.	• Digital agriculture being shaped solely by the private sector, with its benefits and innovations benefiting only industrialized farms. • Missed opportunity to provide credible, trusted data and analysis on global food security to align public, private, and non-profit goods towards food, land, and water systems transformation.
			• Limited use of digital agriculture tools and approaches becomes a missed opportunity to engage youth.
	Operations risk	• Without safeguards and standards in place, increased digital activity can increase use of —and, perhaps more damaging, trust in—poorly designed and validated tools that may be developed using poor quality data.	• Missed opportunity to improve overall programmatic implementation and an inability to communicate and demonstrate the impact of our work.
	Technology risk	• Potential for mishandling or inadequate protection of sensitive data. • Poorly implemented links to public information systems create misperceptions of CGIAR in the wider sector.	• Misidentified and untraceable (genetic) material in collections. • Uncertainties around access and benefit sharing issues will affect research activities and partnerships.
	Financial risk		
		• Getting the privacy and ethics dimension wrong, which could put stakeholders at risk (including privacy breaches), erodes the trust of CGIAR funders.	• Continued wrong interpretation of the data.
		• Increased risk of violating the privacy of users or vulnerable groups.	• Privacy violations.
		• The paradox of exposure (increasing visibility increases risks to vulnerable populations).	• Digital tools of poor relevance to women and other marginalized groups.
		• Gender blind interventions.	• Lack of responsiveness to the digital needs of beneficiaries and partners.

DIGITAL INTERVENTIONS IN RESEARCH		ACTION	NO ACTION
	DIGITAL TRUST AND COLLECTIVE ACTION		
	Regulatory / ethical risks	• Less direct interaction with human subjects increases the risk of the unethical use of technology, eroding the trust of our stakeholders.	
	LEADERSHIP		
Type of risk	**Strategic / Reputational risk**	• Research becomes automated, less collaborative, and more extractive with our partners and stakeholders.	• Insufficient attention to breaking down silos and consolidating good practices can lead to balkanization and missed opportunities to collaborate and build capabilities. • A unifying CGIAR digital strategy is not validated and adopted, resulting in siloed digital capabilities and a missed opportunity to leverage the digital revolution in research and impact as a unified organization.
		• Over-optimistic about what big data and algorithmic methods can deliver.	
			• Limited use of digital agriculture tools and approaches becomes a missed opportunity to engage youth.
	Operations risk	• Proliferation of technologies and services can become a burden for researchers who may become overloaded unless some standardization is developed.	• Missing opportunities to leverage improved digital capabilities due to postponed investment(s).
	Technology risk		• Digital governance does not effectively bridge research informatics and IT infrastructure and services to guide the best data and technology choices that support the digital strategy.
	Financial risk		• A shift of funding if data management is not continually enhanced.
	Regulatory / ethical risks	• The paradox of exposure: increasing visibility increases risks to vulnerable populations.	• Digital tools of poor relevance to women and other marginalized groups.
		• Gender blind digital interventions may exacerbate social exclusion.	• Lack of responsiveness to digital needs of beneficiaries and partners
			• Obsolete information systems not reaching the target audience.
			• Degraded organizational digital capacity can erode trust in the organization.

DIGITAL INTERVENTIONS IN RESEARCH		ACTION	NO ACTION
		SKILL AGENDA	
Type of risk	**Strategic / Reputational risk**	• Visualizations underlying research are not neutral; without the proper expertise, there is the risk of losing sight of the underlying research.	• Underdeveloped skills and experience can lead to erroneous conclusions and bad policy.
			• Decreased ability to attract top tech talent.
	Operations risk	• Existing staff becomes alienated.	• Inefficiency and not being able to speak the same language.
	Technology risk		• Not capturing all key data, because of limited digital capabilities.
	Financial risk		• CGIAR does not claim the full value of its data and its ability to deliver the research and impact is degraded, eroding funding relationships.
	Regulatory / ethical risks		• Limited capacity to securely and responsibly manage overwhelming amounts of data increases the risk of non-compliance.
		INFRASTRUCTURE	
Type of risk	**Strategic / Reputational risk**		• CGIAR falls behind other research organizations and the private sector in having the best possible digital infrastructure to execute its overall strategy.
	Operations risk		• CGIAR operations remain siloed and opportunities for efficiency are lost.
	Technology risk	• Constant cybersecurity threats.	• Constant cybersecurity threats.
	Financial risk	• Increased demand for costly technologies and services CGIAR may not be able to afford (e.g., proprietary imagery can be extremely expensive).	• Using technologies that could become outdated very quickly and may be treated as sunk costs.
		• Vendor lock-in when using commercial services.	
			• Wasting resources due to lack of knowledge.
	Regulatory / ethical risks		

DIGITAL INTERVENTIONS IN RESEARCH		ACTION	NO ACTION
		DATA MANAGEMENT	
Type of risk	**Strategic / Reputational risk**		
	Operations risk	• Increased use of digital tools without close attention to the data feeding them can result in poor quality output or services.	• Lower-quality research products because of limited ground-truthing data.
	Operations risk	• Without safeguards and standards in place, increased digital activity can increase the use of--and, perhaps more damaging, trust in--poorly designed and validated tools that may be developed using poor quality data.	• Poor overall programmatic implementation degrades and there is an inability to communicate and demonstrate CGIAR researchers' impact.
	Technology risk		• Misidentified and untraceable (genetic) material in collections.
	Financial risk		• CGIAR not claiming the full value of its data assets erodes its ability to deliver research and impact for its funders.
	Regulatory / ethical risks	• Limited capacity to securely and responsibly manage overwhelming amounts of data.	• CGIAR data assets become unusable with insufficient data management; otherwise, it could be an asset for the organization and the sector. • Increased risk of wrong interpretation of the data without the enforcement of strong cross-cutting data standards.
		ECOSYSTEM THINKING	
Type of risk	**Strategic / Reputational risk**	• Poor data sharing with private sector partners can become overly complex and may undermine CGIAR's mission of producing and delivering international public goods in agricultural research. • Misperception of new digital alliances are antithetical to the public-interest mission of CGIAR.	• Data silos continue or are reinforced, resulting in missed opportunities for research engagement and quality, which undermines a data sharing culture.
			• Developing digital services that cannot be adequately scaled.
	Strategic / Reputational risk	• Increased use of digital technologies and tools may lead to increased visibility. If not properly handled, CGIAR's position on sensitive issues such as data assets, genetic resources, or genetic engineering could be misinterpreted.	• Digital agriculture being dominated by the private sector, with its benefits and innovations benefiting only industrialized farms.

DIGITAL INTERVENTIONS IN RESEARCH		ACTION	NO ACTION
Type of risk	**Operations risk**	• Researchers become consumed with the technology and tools and pay more attention to them than to research hypotheses and questions. • Vendor lock-in with data or service providers.	• Stagnation in developing new methods.
	Technology risk	• Overreliance on complex tools that are difficult to use in real life, produces poor quality and/or not fit-for-purpose tools with low end-user uptake.	• Missing the rapid shift in the various digital ways of working precipitated by the COVID-19 crisis.
		• Choosing digital technologies or platforms for CGIAR communications that are not fit-for-purpose and will therefore not be used or will be ineffective.	
	Financial risk		• Data redundancy and risk of expensive, continually duplicative data collection.
			• Uncertainties around access and benefit sharing issues will affect research activities and partnerships.
	Regulatory / ethical risks	• Increased risk of violating the privacy of users or vulnerable groups when linking to a larger digital ecosystem.	
		• Loss of human interaction increases the risk of unethical study design related to human research subjects.	
		• Getting the privacy and ethics dimension wrong could put stakeholders at risk, which might include privacy breaches.	
	DIGITAL INNOVATION STRATEGY AND MANAGEMENT		
	Strategic / Reputational risk	• Trying to reinvent what the private sector already has, creating stakeholder alienation as well.	• CGIAR loses visibility and opportunities to engage with stakeholders, undermining its relevance.
		• Running afoul of our international commitments unless digital innovation is well-targeted and managed.	

DIGITAL INTERVENTIONS IN RESEARCH		ACTION	NO ACTION
Type of risk			• A missed opportunity to tap into the surge of digital innovation at the intersection of life sciences and digital technologies to have the impact in a timely manner and at the needed scale to achieve the SDGs.
			• Missed opportunities to build more effective decision making across One CGIAR.
	Strategic / Reputational risk		• Missed opportunities to leverage digital technologies and partnerships to reach greater impacts at scale, leveraging the global footprint of CGIAR.
			• Loss of potential to enhance the insight of traditional data (household surveys, census, etc.) and to generate new questions/knowledge.
			• Missed opportunity to help close the technology gap between the North and South.
		• Loss of focus with researchers engaging in so many efforts.	• Poor coordination across CGIAR and with external partners increases the risk of duplication of efforts.
	Operational risk	• Falling into tech-solutionism and prioritizing the desire to be innovative over seeking to fully understand problems can lead to oversaturating the market with digital products.	• A missed opportunity to build organizational capacity on the use of new digital technologies.
			• Low productivity, low innovation.
			• Poorly defined decision authority could undermine the ability of specific teams or groups to implement the digital strategy system wide.
	Technology risk	• Over-investment in communications tools or projects that may generate little traction.	• Missing key technology, tools, and capabilities to stay abreast of and leverage the data deluge.
	Financial risk	• Initiatives will need to stop due to fluid, inconsistent funding.	• Reduced visibility and engagement can reduce the ability to attract new funding sources.
		• Underestimating challenges and costs.	
	Regulatory / ethical risks	• Increasing the digital divide and possibly targeting incorrect technology beneficiaries.	• Not enforcing data ethics or responsible/ responsive governance (and the ensuing risks).

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