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Information and Communication Technologies—Opportunities to Mobilize Agricultural Science for Development

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ABSTRACT

Knowledge, information, and data—and the social and physical infrastructures that carry them—are widely recognized as key building blocks for more sustainable agriculture, effective agricultural science, and productive partnerships among the global research community. Through investments in e-Science infrastructure and collaboration on one hand, and rapid developments in digital devices and connectivity in rural areas, the ways that scientists, academics, and development workers create, share, and apply agricultural knowledge is being transformed through the use of information and communication technologies (ICTs). This paper examines some trends and opportunities associated with the use of these ICTs in agricultural science for development.

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Abbreviation: ICTs, information and communication technologies.

Key trends influencing agricultural research organizations include: First, pervasive computing and low-cost connectivity is transforming the ways that science and development are conducted. Second, massive processing power is accessible through "clouds" of Internet and computing services, providing sharable tools, applications, and intelligently linked content and data. Local computing capacities are no longer a barrier to gain access to world-class computing services. Third, science can call on an increasing ability to collect, analyze, and reuse massive, distributed collections of data. Fourth, individuals and amateurs are increasingly able to create and manage sophisticated information and knowledge. This "democratization" of science and the Internet draws many more people and institutions into research and development processes.

In a review of current work on "data-intensive computing" for science (Hey et al., 2009), the editors argue that scientific breakthroughs will increasingly be powered by advanced computing capabilities that help researchers manipulate and explore massive data sets. Almost everything about science is changing because of the impact of information and communication technologies.

Information and communication technologies (ICTs) are being applied to all parts of the research for development

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continuum that connects agricultural science with agricultural and rural change.

On the one hand is "e-Science" (or e-Research), characterized by global collaboration and the next generation of infrastructure that will enable it. On the other is "m-Agriculture"—that uses mobile digital devices such as phones, laptops, and sensors that put ICTs, connectivity, and applications into the hands of rural communities. Between these extremes, ICTs are transforming agricultural extension (in the United States and the Philippines for example), facilitating the delivery of education and learning in universities and through open distance education (see the work of the Commonwealth of Learning), helping to empower the rural poor in developing countries (see Heeks, 2009), and powering a wide array of agricultural finance, credit, market, weather, and other services delivered by public and private organizations (see www.e-agriculture.org and http://iaald.blogspot.com [verified 22 Dec. 2009] for examples).

Drawing on discussions and materials prepared for a workshop held in June 2009, this paper examines some trends and opportunities associated with the use of these ICTs in agricultural science for development. Significant trends include:

- **Increasingly "ubiquitous" connectivity along value chains**—As illustrated by Ballantyne (2009) and Gakuru et al. (2009), people are making use of a wide range of devices and platforms to access and share agricultural knowledge: from the Web to phones, radio, video, and text messaging. Most scientists already work in knowledge-rich environments where good digital and social connectivity is the norm; farming communities, probably using different devices from those we see today, will be far more connected than now. The widespread use of mobile phones by farmers and others to get market and weather information is well documented (CTA, 2009). Multiple connectivity paths widen the potential reach of science; they also widen the potential to include the knowledge of rural communities into science.
- **Increasingly "precise" applications and tools**—ICTs and digital signatures or labels of various types are being used to track products from producer to consumer; to monitor local soil, weather, and market conditions; to tailor data and information services to the demands of a specific audience or individuals (Mondal and Basu, 2009; Wolfert et al., 2009). Future applications will come in many shapes and sizes, to suit even the most specialized needs.
- **Increasingly "accessible" data and information**—Vast quantities of public data and information held by institutions and individuals are becoming visible, publicly accessible, and reusable at the click of a device. Beyond the open-access movement that mainly focuses on scientific literature, there is a broader trend to make publicly funded data, software, and information more open (Hey et al., 2009; McLaren et al., 2009). Beyond shorter-term challenges to make these data and information widely and openly accessible (through for instance the Coherence in Information for Agricultural Research for Development initiative, the information and communication management initiative of the Global Forum on Agricultural Research, or the "Triple A" effort of the Consultative Group on International Agricultural Research), more intermediary skills and applications will be needed to help harvest, make sense of, and add value to the fast-growing layers of data and information that are becoming available.
- **Increasingly "diverse" set of applications available across digital clouds**—The digital "identities" of scientists and their collaborators are starting to give them access to a wide range of online tools and applications, accessible from any location and across different devices, enabling collaboration across boundaries as never before (Werth, 2009). As outlined by Porcari (2008), local firewalls and server configurations conditions will no longer be a constraint to global sharing.
- **Increasingly "interconnected" tools and knowledge bases**—Hannay (2009) argues that the interconnectedness of scientific data and information will be a key feature of future science. In agriculture, as illustrated by GTZ (2008), different communities are starting to connect and share their knowledge with each other, along research cycles and value chains and across disciplines. Increasing attention to innovation systems approaches in agricultural development, as discussed by Hall (2006), Kristjanson et al. (2009), and the World Bank (2007) among others, points to a much wider and more diverse involvement by different "actors" in science and research, such as farmers, traders, and politicians. As Waters-Bayer et al. (2006) argue, connecting these actors so they can interact enhances such innovation processes.

FRONTIERS IN ICTs

Hardware and Connectivity

Moore's Law that the number of transistors that can be placed inexpensively on an integrated circuit is growing exponentially, the number of transistors doubling approximately every 2 yr, has so far held. The same law can be applied to processing speeds of microprocessors, memory capacity, and the number of pixels that a digital camera can process. Memory storage capacities in magnetic and optical media have also increased exponentially and solid state drives are already commercialized. Connectivity between computers and through the Internet has similarly increased in bandwidth. The rates at which data can be transmitted, both within buildings and across long distances, grows without apparent limit and with ever reducing costs. Parallel and Grid computing has demonstrated huge potentials of processing power available for use on the desktop of an average computer user, and this will be multiplied manyfold with memristors (already prototyped), photonic and quantum computers (still in the research phase). We are seeing a boom in handheld devices that interface with existing systems.

Ubiquitous Telecommunication Infrastructure

Flowing from the falling costs of all things digital, there has been a steady flow of investment into communications infrastructure around the world. Cell phone and broadband (wired and wireless) Internet networks carrying both voice and data are being deployed in even the poorest countries, and with time will expand to cover most rural areas. These systems are sophisticated; they increasingly allow agriculture and agricultural research to take improved connectivity for granted.

Utility or "Cloud" Computing

The combination of progress in computing hardware, system software, and Internet communications has now enabled the construction of general-purpose data centers that can be reconfigured by command to support any software application in minutes. There are already data services that allow a user to have hundreds or thousands of computers at their command, and yet pay for them by the hour or minute, without owning or operating the hardware themselves. The costs are far less than even falling hardware prices would suggest because the cost of the data center can be shared among many users. In effect, the data center acts like a utility, providing as much computing as requested at just the times when needed. Since these data centers are shared over the Internet, they are sometimes called computing "in the cloud." These "cloud" data centers are the natural repository for shared data sets, so that users in any location or institution can instantly access, analyze, and interpret public information goods without the need to move the data to their own facilities. This can enable a researcher in any location to work with data as well as with any other researcher, which can lead to new kinds of collaboration and new sources of project direction.

Software and Content Management

An important frontier achieved through more complex processors, processing speeds, memory capacity and connectivity has been the development of agents, sensors, and devices such as radio-frequency identification tags (RFIDs) that are now reshaping how humans work and interact. The semantic Web and its related techniques and applications (e.g., ontologies) currently work in this way, helping reshape machine-to-machine interaction and the way computers retrieve, manage, and share knowledge on the Web.

The science of pragmatics—the practical interpretation and use of signs by agents or communities within particular circumstances and contexts—and going beyond conventional semantics, is now allowing ICTs to be used in much more supportive ways. This has been demonstrated in diverse areas such as health, scientific research, and business management in modeling, simulation, forecasting, and visualization, and has implications for agriculture. These potentials bring new challenges on how we understand this new pervasive computing landscape and how we can make use of collective and distributed forms of intelligence.

Interactions with Biology

The interaction of ICTs with biology, biotechnology, nanotechnology, and new materials is enabling the development of high-quality information from diverse entities and sources and which is self-organizing. This self-organizing collective intelligence—living information—presents new frontiers in effective use and application. Continuous advances in ICTs and biology are enabling developments where the relationship between these two disciplines faces a paradigm shift: from ICTs that mimic biology to ICTs that use biology for information processing. Progress in synthetic biology—the study of the design and building of novel biological functions and systems—is bringing progress in systematic design methodologies and manufacturing processes. The potential to interface ICTs with biological systems at the micro/nano scale is now emerging.

It can further be argued, even with current knowledge, that bio- and nanotechnology, material sciences, and ICTs will together define the core direction of agricultural science, research, and technology in the future—by having an impact on plant and animal breeding and improvement, agricultural production systems, risk management and aversion, sustainable use of natural resources, protecting the environment and agricultural market chains, and in agricultural innovation in general.

ICTs IN AGRICULTURAL SCIENCE FOR DEVELOPMENT

ICTs and Agricultural Production

An area of application for ICTs is in improving, through better management, the efficiency and sustainability in using inputs—land, soil nutrients, feed and fodder, water, energy, pesticides, labor, and most importantly, information and knowledge—in agriculture. The ICTs also help reduce the negative effects of pests and disease and enable aversion and mitigation of risks such as from inclement weather, droughts, floods, and long-term change in climate. Through innovation, ICTs continue to contribute to improving throughput of farming systems, increasing the quantity, quality, and marketability of outputs (e.g., food, energy, and biomaterials), supporting their marketing and enabling their effective and efficient consumption by households and communities and their ultimate recycling. The ICTs helped pave the way for consumers to decide which products they can "responsibly" purchase, which seem to have higher food miles, and those whose production and safety can be traced all the way back to the fishpond.

For the small, resource-poor farmer and producers in economically developing countries, these applications of ICTs have not yet become mainstream. The economic returns from agriculture and access to affordable technology useful in small-farms operations are the main constraints in more widespread use of ICTs in smallholder agricultural production.

ICTs and Agricultural Science, Research, and Technology Generation

The current application of ICTs in agricultural science, research, and technology generation can be clustered around:

- **Data collection**—Enabling collection of agricultural and environmental data from biological and environmental sources, with or without human interaction. The data are subsequently analyzed and manipulated to feed auxiliary applications or to conduct studies.
- **Number crunching**—Enabling management, sharing, and processing of large data sets, modeling and simulation, image processing, and visualization that contribute to plant and animal breeding and improvement, bioinformatics, agricultural meteorology, plant, animal, and zoonotic diseases epidemiology, farming systems research, market chain analysis and management, etc.
- **Geospatial applications**—Enabling data and information related to geography and space to be managed, processed, and visualized and contributing to land and water use planning, natural resources utilization, agricultural input supply and commodity marketing, poverty and hunger mapping, etc.
- **Decision support and knowledge-based systems and robotics—**Enabling data and information to be organized with added experiences of experts to mimic, multiply, and use expertise, especially in searching information and data semantically, in problem diagnosis, and in farm and agricultural process automation.
- **Embedded ICTs in farm equipment and processes—**Enabling greater efficiencies in farm equipment and agricultural processes and in what is termed "precision agriculture," as also in agricultural products transport and marketing such as the use of RFIDs, wireless Internet, and cellular telephony in labeling, traceability, and identity preservation.
- **Connecting communities and enabling learning—**Using ICTs to connect communities of farmers, researchers, and all connected to agriculture. ICTs are already playing a significant role in connecting scientists and researchers to communicate with each other and in scientific and technical publications. Use of ICTs to connect farmers and producers to new agricultural knowledge and technology and in problem resolution has been tested and found very useful, so much so that ICTs are now considered to be transforming agricultural extension (examples are the Pinoy Farmers' Internet project of the Open Academy for Philippine Agriculture, the "Digital Green" project in India, and the eXtension Initiative in the United States). Through enabling access to text, graphics, audio, and video objects in an integrated manner, ICTs have also helped education systems by broadening access to learning and by improving the quality of the classroom experience.

ICTs and Agricultural Innovation

Progress in hardware, software, connectivity, and integration of computing systems enables new forms of data gathering, both human assisted and automated. It is bringing new capacities for processing data and information dissemination. In future, this process of connecting communities to new knowledge and information is likely to accelerate with advanced technologies that bring far greater processing powers, robust, reliable storage capacity, and connectivity.

This progress will also extend new forms of participatory science and research, extension, and learning to those within agricultural communities who are not yet included in these processes. Extension, as it is understood now as being "linear" from research to farmer through extension agents will be as in a network with pluralistic sources, formats, and users of information and knowledge (Gakuru et al., 2009; Gandhi et al., 2009). Learning will be ubiquitously available and pervasive for all in an agricultural community. It will change the realm of agricultural science, where it will not only be the formally educated scientists who bring new technological innovations but whole communities who do so. All within an agricultural community will be producers and consumers of information and innovations.

The ICTs, as described above, can also enable more connected agricultural communities and it is envisaged that these connected communities will practice science and lead agricultural innovation. Participatory community-driven and -led agricultural innovation through extensive use of ICTs will lead to new technologies such as seeds, breeds, and animals customized to meet the specific needs of particular communities, participatory watershed management, participatory plant and animal pest and disease monitoring and surveillance, etc.

ICT TRENDS INFLUENCING AGRICULTURAL SCIENCE FOR DEVELOPMENT

In general, the most significant impact of ICTs on agricultural technology generation will be in connecting and engaging communities in participatory agricultural innovation. Science will be able to come out of its "silos." New agricultural processes and technologies to solve agricultural problems will emerge through innovation with user communities, thus eliminating many of the constraints facing agricultural science, research, and technology generation.

Other significant trends include:

- Information and communication technologies, devices, and software are becoming much cheaper and more affordable, even in rural areas.
- Connectivity is becoming more pervasive and "mobile"—people can connect and interact in real time with other people and data across a broad range of wireless, mobile, and other devices. And more and more of the devices are becoming smart and intelligent—capable of multiple operations.
- Geospatial and "neogeographic" functionalities, applications, and tools are spreading and becoming ubiquitous, offering pinpoint location and data collection and sharing possibilities.
- More and more services will be provided across the Internet through so-called "cloud" computing, obviating the need for sophisticated local ICT systems and capabilities.
- As the quantity of data and information grows, new ways to organize, navigate, mine, share, visualize, and "mash" it up will emerge, creating new possibilities and services.
- Digital applications and tools are being applied to enable and extend traditional "human" processes such as communication, collaboration, and analysis.
- Within agriculture and science, new thinking and approaches are emerging around "end user innovation," focused on knowledge, value chains, innovation systems, etc.
- Scientists increasingly use and depend on ICTs in their daily work: computers, enhanced ICT literacy, and connectivity are part of the "basic" package.

ICT OPPORTUNITIES FOR AGRICULTURAL SCIENCE FOR DEVELOPMENT

Opportunities that agricultural science could gain from increased use of ICTs include:

- Through ICTs, the possibility to make agricultural research and development processes more inclusive, enhancing communication among all agriculture stakeholders. As reported by the CGIAR "KS in Research" project (www.ks-cgiar.org [verified 22 Dec. 2009]), this provides greater potential for horizontal knowledge sharing among different stakeholders, increasing the likelihood of collaboration.
- Rural communities and farmers empowered through ICTs to enhance their own livelihoods and other opportunities. New types of ICT-enabled rural businesses and entrepreneurs are emerging, providing a range of new services and livelihoods.
- Delivery of various ICT-enabled services to rural people: such as market access, access to international export markets through ICT traceability systems, mobile financial services, mobile extension services.
- Improved capabilities to create and store data and information; gaining rapid access to it.
- Enhanced two-way flow of timely, highly targeted, location-specific, and location-intelligent information.
- Increased possibilities for public and community to be lay data collectors; farmers and producers can contribute data directly to national and international initiatives. This will also facilitate stable and continuous farm (field) data acquisition.

Realizing the Potential of ICTs in Agricultural Science for Development

Priorities to realize these opportunities include:

- Improve communications infrastructure and bandwidth, investing in lower-cost hardware, software, and applications that connect science right along the development chain.
- Increase and improve formal education and training in information and communication sciences that contribute to innovation in the use of new ICTs in agriculture.
- Extend the generation and dissemination of data and information content as a "public good" that is widely accessible and is licensed to be easily reused and applied.
- Support applications that integrate data and information or foster the interoperability of applications and information systems, allowing safe and ethical access while protecting necessary rights.
- Encourage the effective uptake and use of data, information, and knowledge, particularly focusing on capacity-building dimensions necessary for the outputs of science to have impacts.
- Support innovation in the workflows, processes, and tools used to create, share, publish, visualize, and connect the outputs of agricultural science and the people engaged in it.
- Promote open access to research documents and data, the use of open intellectual property licenses, and

adoption of open standards that facilitate interoperability across systems. Alongside these changes, develop incentives and reward schemes that promote open sharing and open behavior.

Further Reading

The Fate of Agriculture? (Balaji, 2009).

EFITA Questionnaire on ICT Adoption Trends in Agriculture (Gelb, 2009a).

How Are Innovations Adopted—A Case Study of ICT (Internet) for Agriculture (Gelb, 2009b).

ICT Adoption Dangers and Pitfalls (Gelb, 2009c).

The Impact of ICT on Agricultural Science and Scientific Reasoning (Gelb, 2009d).

What are ICTs for Agriculture? (Gelb, 2009e).

Semantic Interoperability (Keizer and Pesce, 2009).

Changing the Emperor: ICT's Transforming Agricultural Science, Research and Technology (Manning-Thomas, 2009).

Innovative IT Tools for Farm Management—Benefits and Beneficiaries (Manukyan, 2009).

ICTs Role in Improving Market Access for Small Scale Farmers (Nichterlein, 2009).

ICTs Transforming Agricultural Science, Research and Technology Generation (Ninomiya, 2009).

Ubiquitous Networks and Cloud Computing (Porcari, 2009).

Managing Agriculture Knowledge: Role of Information and Communication Technology (Rafea, 2009).

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