OPINION

Smart farming is key to developing sustainable agriculture

Achim Walter[a,1], Robert Finger[b], Robert Huber[b], and Nina Buchmann[a]

Agriculture has seen many revolutions, whether the domestication of animals and plants a few thousand years ago, the systematic use of crop rotations and other improvements in farming practice a few hundred years ago, or the "green revolution" with systematic breeding and the widespread use of man-made fertilizers and pesticides a few decades ago. We suggest that agriculture is undergoing a fourth revolution triggered by the exponentially increasing use of information and communication technology (ICT) in agriculture.

Autonomous, robotic vehicles have been developed for farming purposes, such as mechanical weeding, application of fertilizer, or harvesting of fruits. The development of unmanned aerial vehicles with autonomous flight control (1), together with the development of lightweight and powerful hyperspectral snapshot cameras that can be used to calculate biomass development and fertilization status of crops (2, 3), opens the field for sophisticated farm management advice. Moreover, decision-tree models are available now that allow farmers to differentiate between plant diseases based on optical information (4). Virtual fence technologies (5) allow cattle herd management based on remote-sensing signals and sensors or actuators attached to the livestock.

New technologies, such as unmanned aerial vehicles with powerful, lightweight cameras, allow for improved farm management advice. Image courtesy of Shutterstock/Kleir.

Taken together, these technical improvements constitute a technical revolution that will generate disruptive changes in agricultural practices. This trend holds for farming not only in developed countries but also in developing countries, where deployments in ICT (e.g., use of mobile phones, access to the Internet) are being adopted at a rapid pace and could become the game-changers in the future (e.g., in the form of seasonal drought forecasts, climate-smart agriculture).

Such profound changes in practice come not only with opportunities but also big challenges. It is crucial to point them out at an early stage of this revolution to avoid "lock-ins": advocates and skeptics of technology need to engage in an open dialogue on the future development of farming in the digital era. Only if aspects of technology, diversity of crop and livestock systems, and networking and institutions (i.e. markets and policies), are considered jointly in the dialogue, should farming in the digital era be termed "smart farming."

Ample Opportunities

Smart farming reduces the ecological footprint of farming. Minimized or site-specific application of inputs, such as fertilizers and pesticides, in precision agriculture systems will mitigate leaching problems as well as the emission of greenhouse gases (6). With current ICT, it is possible to create a sensor network allowing for almost continuous monitoring of the farm. Similarly, theoretical and practical frameworks to connect the states of plants, animals, and soils with the needs for production inputs, such as water, fertilizer, and medications, are in reach with current ICT globally.

Smart farming can make agriculture more profitable for the farmer. Decreasing resource inputs will save the farmer money and labor, and increased reliability of spatially explicit data will reduce risks. Optimal, site-specific weather forecasts, yield projections,

[a]Institute of Agricultural Sciences, Eidgenössische Technische Hochschule Zürich, 8092 Zurich, Switzerland; and [b]Agricultural Economics and Policy Group, Eidgenössische Technische Hochschule Zürich, 8092 Zurich, Switzerland

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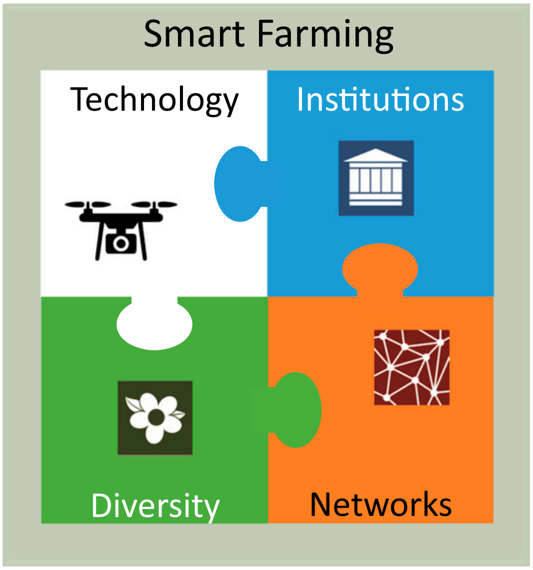
[1]To whom correspondence should be addressed. Email: achim.walter@usys.ethz.ch.



Only by considering new technologies in conjunction with a diversity of crop and livestock systems, as well as the relevant markets and policies, can farming in the digital era become smart farming.

and probability maps for diseases and disasters based on a dense network of weather and climate data will allow cultivation of crops in an optimal way. Site-specific information also enables new insurance (7) and business opportunities for the entire value chain, from technology and input suppliers to farmers, processors, and the retail sector (8) in developing and developed societies alike. If all farming-related data are recorded by automated sensors, the time needed for prioritizing the application of resources and for administrative surveillance is decreased.

Smart farming also has the potential to boost consumer acceptance. In principle, optimizing management also permits increased product quality (e.g., higher amounts of antioxidants and other secondary metabolites based on optimal fruiting densities in orchards; or physiologically more amenable milk products based on individualized feeding rations of livestock). These products are not only healthier but can also sell at higher prices, a key strategy in using land more efficiently (9). In addition, the transparency of production and processing will increase along value chains because ICT allows registration as to which farm produced a certain product under which circumstances. This offers the potential for new, more direct forms of interaction among farmers and consumers.

Major Challenges

Still, numerous hurdles must be overcome. Among the major questions to be addressed: Who owns the data? ICT that records the input of resources and the output of products does raise questions of property rights and use of data. Business models might create added value by converting spatially explicit big data into information and advice not only for farmers but also for regulatory authorities who may use the data for surveillance and control. Governments must establish a regulatory architecture that guarantees high-quality data while at the same time fostering trust among all actors involved. The potential misuse of data creates additional legal and ethical challenges for regulation and monitoring (10).

In addition, ICT will intensify the challenges of responsibility and accountability of new technologies. There must be accountability for mismanagement or errors leading to economic and environmental consequences. For example, who is responsible for traces of fungicides left behind on harvested fruits when that fungicide has been applied too late? Is it the farmer, the provider of the software, or the producer of the sensor? Such scenarios are far from being straightforward, as recently exemplified by accidents with self-driving cars (11).

High costs to adopt technology for individual farms and limited knowledge and skills can be significant adoption hurdles (12, 13), especially in developing countries. Thus, the access to the latest technology may remain restricted to big and industrialized farms. The benefits of ICT might be limited to industrialized countries and focused on the production of well-known and widely grown crops, such as wheat, maize, and rice. This also increases the risk of unsustainable intensification practices (14). In an industrialized setting, disease outbreaks may be delayed by fungicides, but this comes with an increased risk of generating resistant fungal strains that can then act even more devastatingly once they have overcome prevention measures.

The transition to industrialized societies has led to rapid decreases in farming occupancy rates to values of 2% and less of the population in Europe and North America. Digitalization of agriculture might influence employment opportunities and job profiles of farmers and farming-related professionals even further. Will this development motivate or discourage talented persons from entering into the field of agriculture? Will the potential loss of farmers' responsibility to data-managing robots and ICT systems increase or decrease the recognition and the appreciation of this profession? Another emerging challenge will be combining the farmers' knowledge and experiences with these new technologies.

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A Way Forward

Smart farming can provide a concerted path out of locked-in technologies and practices characterized by strong polarization and market segmentation. It offers a path toward sustainable agriculture by diversification of technologies, crop and livestock production systems, and networks across all actors of the agri-food sector. There is no single policy approach that can achieve this vision, which supports and facilitates the appropriate use of ICT technology. Rather, the idea is to identify the dominant mechanisms that constrain or threaten a sustainable use of the technology and to select the most appropriate actions in developed and developing countries (15).

This may result in better access to capital in some cases and to specific support of investments in others. Moreover, the support of cooperatively used farm-monitoring technology (e.g., jointly owned unmanned aerial vehicles monitoring fields of entire villages) or investments in education and training may also support the sustainable use of these technologies. In all cases, however, the policy environment should provide a clear, legal setting that allows for effective ownership and user rights.

The possibilities of the digital era might lead to new forms of diversification on farms. Similar to the debate and conceptualization of "smart cities," the possibilities of ICT will likely not lead to one globally uniform and rapidly accepted farming system but to a diversity of farming systems. Technical innovations contributing to diversification are facilitated by management advice if given with high reliability and clarity, even if farmers have not produced a certain crop before. Current problems with resistance, for example to antibiotics and pesticides, could be avoided with a higher diversity of production systems.

However, although the "Internet of Things," including agricultural machinery, can be used to manage standard farming situations, the farmer still needs to serve as both scientist and watchdog, keeping an eye out for unforeseen situations. Farmers can invest the time freed up by digitalization in treatment of diseases or in monitoring and treating livestock in a more individualized way. Crop pests and diseases need only be tackled when certain thresholds—determined with new ICT applications—are reached. Still, such an intentional increase of diversity requires that consumers, farmers, and decision-makers are convinced of the benefits of these technological advantages. Moreover, it requires a new system of data transfer with differentially regulated transparency functions: the administrative and production data being transferred to suppliers and the government must be transparent to farmers. And it must be possible for the consumer to obtain insight into the entire food production chain.

ICT enables farmers to exchange information, establish cooperation and peer review, and maybe even develop informal information systems that can complement the formal information system of controlling authorities. Such a flow of information among farmers and between farmers and consumers would be scale-independent and would not be restricted by state borders. Clear signs for an adoption of such systems can be seen already in developed and developing countries, with social media platforms and initiatives such as iCow (www.icow.co.ke/), an example from Kenya. Institutional innovations would be possible, leading to networks of farmers who are more self-organized and flexible than today. Joint use of machinery and applications similar to Airbnb and Uber can promote private exchange of sowing, maintenance, and harvesting operations. Yet, because regulatory authorities need to have access to some aspects of the data gathered, clear policies and a transparent data-management system will be required.

ICT and data management can provide novel ways into a profitable, socially accepted agriculture that benefits the environment (e.g., soil, water, climate), species diversity, and farmers in developing and developed countries. But this can only happen with the proactive development of policies supporting the necessary legal and market architecture for smart farming, with a dialogue among farming technology supporters and skeptics, and with careful consideration of emerging ethical questions.

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