Identifying priorities to leverage smart digital technologies for sustainable crop production

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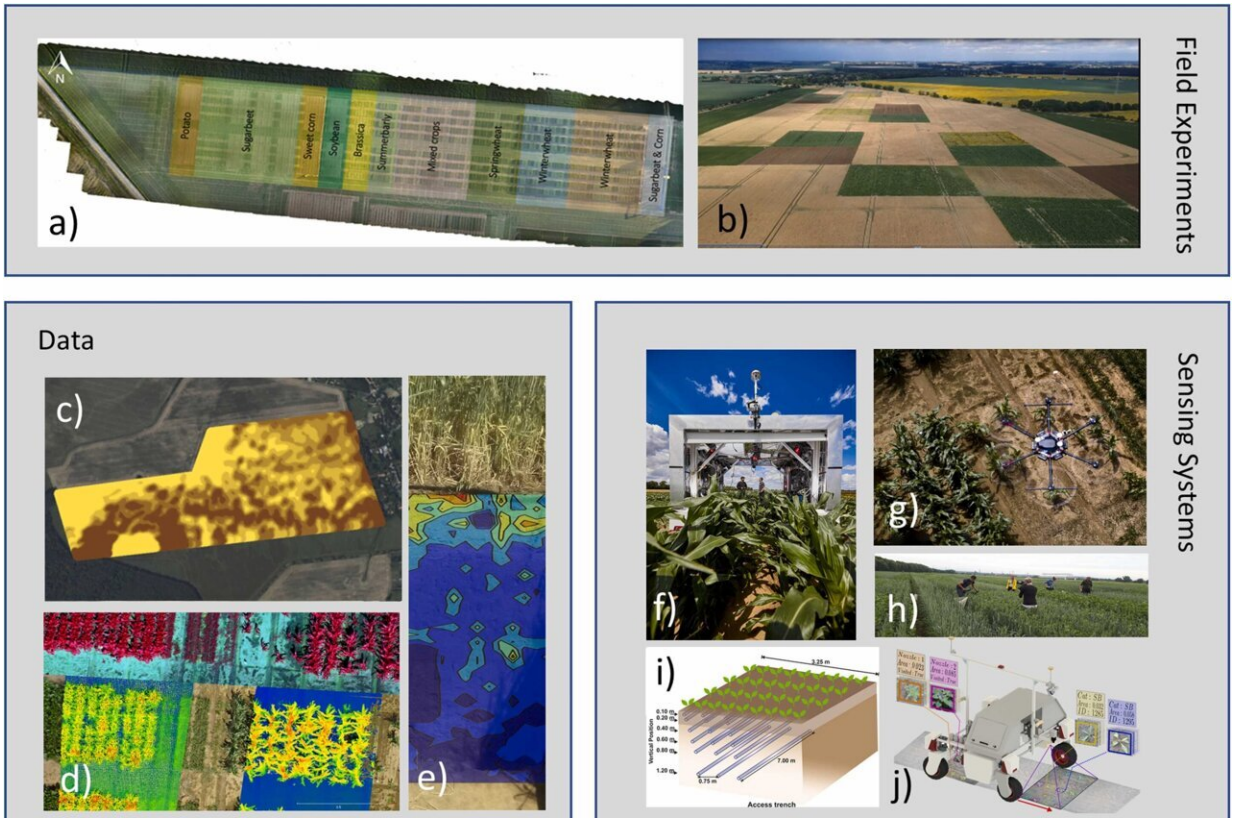

a) PhenoRob Central Experiment, Bonn, Germany b) Patch Crop Experiment (photo by H. Schneider, ZALF PR) c) topsoil clay content (proximally sensed soil electrical resistivity, Geophilus), kindly provided by Anna Engels d) Combination of UAV Lidar, UAV multispectral imagery, and in-field mobile laser scanning e) Root distribution f) Ground robot with high-resolution optical sensors (photo by V.Lannert) g) UAV system (photo by V. Lannert) h) Classical

fieldwork in a crop mixture experiment i) Scheme of the rhizotron facility at Selhausen, kindly provided by Lena Lärm j) Robot for targeted weed management (Ahmadi et al., 2022) k) Schematic crop model output showing the relationship between irrigation water input and yield l) Functional–structural plant models (Zhou et al., 2020) m) Agent-based model to upscale technology adoption. Credit: *European Journal of Agronomy* (2024). DOI: 10.1016/j.eja.2024.127178

Drones monitoring fields for weeds and robots targeting and treating crop diseases may sound like science fiction but is actually happening already, at least on some experimental farms. Researchers from the PhenoRob Cluster of Excellence at the University of Bonn are working on driving forward the smart digitalization of agriculture and have now published a list of the research questions that will need to be tackled as a priority in the future. Their paper appears in the *European Journal of Agronomy*.

That the Earth feeds over 8 billion people nowadays is thanks, not least, to modern high-performance agriculture. However, this success comes at a high cost. Current cultivation methods are threatening biodiversity, while the production of synthetic fertilizers generates greenhouse gases, and agricultural chemicals are polluting bodies of water and the environment.

Many of these problems can be mitigated by using more targeted methods, e.g., by only applying herbicides to those patches of a field where weeds are actually becoming a problem rather than treating the whole area. Other possibilities are to treat diseased crops individually and only to apply fertilizer where it is really needed. Yet strategies like these are extremely complicated and virtually impossible to manage at scale by conventional means.

Harnessing high tech and AI to become more sustainable and efficient

"One answer could be to use smart digital technologies," explains Hugo Storm, a member of the PhenoRob Cluster of Excellence. The University of Bonn has partnered with Forschungszentrum Jülich, the Fraunhofer Institute for Algorithms and Scientific Computing in Sankt Augustin, the Leibniz Centre for Agricultural Landscape Research in Müncheberg and the Institute of Sugar Beet Research in Göttingen on the large-scale project geared toward making farming more efficient and more environmentally friendly using new technologies and artificial intelligence (AI).

The researchers hail from all manner of different fields, including ecology, plant sciences, soil sciences, computer science, robotics, geodesy and agricultural economics. In their recently published position paper, they set out the steps that they believe have to be tackled as a priority in the short term.

"We've identified a few key research questions," Storm says. One of these relates to monitoring farmland to spot any nutrient deficiency, weed growth, or pest infestations in real time. Satellite images provide a rough overview, while drones or robots enable much more detailed monitoring. The latter can cover a whole field systematically and even record the condition of individual plants in the process.

"One difficulty lies in linking all these pieces of information together," says Storm's colleague Sabine Seidel, who coordinated the publication together with him: "For example, when will a low resolution be sufficient? When do things need to get more detailed? How do drones need to fly in order to achieve maximum efficiency in getting a look at all the crops, particularly those at risk?"

The data obtained provides a picture of the current situation. However, farmers are chiefly interested in weighing up various potential strategies and their possible implications: how many weeds can my crop withstand, and when do I need to intervene? Where do I need to apply fertilizer, and how much should I put down? What would happen if I used less pesticide?

"To answer questions like these, you have to create digital copies of your farmland, as it were," Seidel explains. "There are several ways to do this. Something that researchers still need to find out is how to combine the various approaches to get more accurate models." Suitable methods also need to be developed to formulate recommendations for action based on these models. Techniques borrowed from machine learning and AI have a major role to play in both these areas.

Farmers have to be on board

If crop production is actually to embrace this digital revolution, however, the people who will actually be putting it into action—the farmers—will also need to be convinced of its benefits. "Going forward, we'll have to focus more on the question of what underlying conditions are needed to secure this acceptance," says Professor Heiner Kuhlmann, a geodesist and one of the Cluster of Excellence's two speakers alongside the head of its robotics group Professor Cyrill Stachniss.

"You could offer financial incentives or set legal limits on using fertilizer, for instance." The effectiveness of tools like these, either on their own or in combination, can likewise be gauged nowadays using computer models.

In their paper, the researchers from PhenoRob also use examples to demonstrate what current technologies are already capable of doing. For instance, a "digital twin" of areas under cultivation can be created and

fed a steady stream of various kinds of data with the help of sensors, e.g., to detect root growth or the release of gaseous nitrogen compounds from the soil.

"In the medium term, this will enable levels of nitrogen fertilizer being applied to be adapted to crops' needs in real time depending on how nutrient-rich a particular spot is," Professor Stachniss adds. In some places, therefore, the digital revolution in agriculture is already closer than one might think.

More information: Hugo Storm et al, Research priorities to leverage smart digital technologies for sustainable crop production, *European Journal of Agronomy* (2024). DOI: 10.1016/j.eja.2024.127178

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