TAB
OFFICE OF TECHNOLOGY ASSESSMENT
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Digitisation of agriculture: technological developments and perspectives

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Summary

- Several innovative agricultural technologies that are based essentially on digital data processing are already ready for practical application or at an advanced stage of development. These technologies include satellite-controlled agricultural machinery, sensor technologies and application techniques with variable dosing of fertilisers and plant protection products, or robots for milking, feeding and manure removal processes.
- Digital stand-alone applications of this kind collect large amounts of process data, thus forming the basis for a far-reaching digitisation of agricultural production.
- Further progress made in digital agricultural technologies might involve fundamental changes in agricultural processes, as can be expected, for example, in the field of arable farming with certain robotic concepts.
- By means of digitisation, the complex agricultural business processes, which are influenced by many imponderable factors, are to be made both more efficient and more sustainable. As a consequence, environmental impacts are to be mitigated.
- At the same time, digital agricultural technologies alone appear to be not sufficient, or in some cases not suitable, to address some major environmental and animal welfare issues in agricultural production.

What is involved

Digital technologies are becoming increasingly important in agricultural practice and meanwhile penetrate all areas of agricultural technology. Digital applications already in use include, for example, satellite-controlled agricultural machinery, sensor systems for variable dosing of fertilisers and plant protection products, robots for automating routine tasks in the barn or drones for the deployment of beneficial insects. While the trend in crop cultivation is towards site-specific or varied farming, in animal production the focus is on measures related to the individual animal such as feeding, milking and performance measurement. In both areas, an increasing level of automation and even autonomous work processes can be observed.

As in many sectors of the economy, digitisation in connection with innovative data analysis processes is opening up new opportunities for data-based control of production processes in agriculture as well. In view of the fundamental, sometimes seemingly incompatible demands that agriculture is currently facing – food security for a growing world population on the one hand, and more sustainable production on the other – the developments and perspectives of innovative agricultural technologies are being discussed intensively. The goal is to use digitisation to make the complex agricultural business processes – which are influenced by many imponderable factors (weather and environmental influences, etc.) – more efficient and at the same time more sustainable. From both an ecological and an economic point of view, this concerns desirable savings in operating resources, but also facilitating the official duty of documentation as well as documentation tasks at farm level.

Digital agricultural technologies – status quo and perspectives

Digital technologies used by agricultural businesses are extremely diverse and heterogeneous. The developments in the four technology fields of sensors, agricultural machinery, drones and robots are of particular importance for the digitisation of agriculture.

Sensors serve as measuring probes for the acquisition of very different process data and thus form a decisive technical basis for the digitisation of agricultural processes. In

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recent years, the number of available sensor systems and their fields of application have increased significantly. In crop production, sensors are used in order to optimise the growth conditions for crops or to secure or increase yields. Of particular relevance in this context are soil sensors (determination of soil conditions, tillage management), nitrogen sensors for site-specific nitrogen fertilisation, weed sensors for differentiated management of weed control and harvest sensors which, as an integral part of harvesting machines, are intended to measure harvest yields and record quality characteristics of the harvested crop. In livestock farming, sensor technologies are used in stabling and pasturing, e. g. for the observation of individual animals (herd management), for milking and feeding processes or for controlling the climate inside the stable (stable management). Currently, a clear trend can be observed in the development of sensor systems towards online procedures, in which the sensor values determine the characteristics of management measures in real time. The measured data from the sensors must be translated into management-relevant parameters by means of interpretation algorithms in order to be able to derive tangible management measures with decision-making algorithms. Despite their increasing deployment, many sensor systems are still stand-alone solutions. This is why perspectives regarding the use of sensors in the agricultural sector can be found primarily in the development of multi-sensor platforms or systems that combine different sensors, as well as for sensor data fusion, i. e. the linking and joint interpretation of data from different individual sensors.

Fig. 1 Autonomous tractor concept – Case IH

Modern **agricultural machinery** is equipped with satellite-supported navigation and – by means of telemetry systems – offers new opportunities for data-based fleet management and automatic documentation of the management measures carried out. Precise localisation (±2 cm) based on satellite positioning is state of the art and widely used. In addition, several assistance functions are provided as standard, e. g. parallel driving systems or automatic section control technology. A new trend is the so-called tractor implement management, i. e. the control of processes in the field (and corresponding tractor functions) by the implement. Current research projects aim at further automation or even fully autonomous operation of agricultural machinery (fig. 1). Reliable detection of static and dynamic obstacles is an important prerequisite for this, but one that has been insufficiently fulfilled so far. Moreover, there is still a considerable need for research, particularly with regard to the automation of agricultural management processes.

State of knowledge regarding environmental impacts

Applications of precision farming can reduce the use of production resources to a varying extent via an increased production efficiency and consequently mitigate environmental impacts:

- in arable farming through site-specific procedures in tillage, nitrogen fertilisation, weed control or sowing as well as variable combat of plant diseases and automated steering systems;
- in the field of animal production through individualised feeding (precision feeding) and automated milking.

Due to the diverse fields of application and procedures, the very heterogeneous conditions of use and complex interactions, there are still major uncertainties regarding the magnitude of the beneficial effects that can be achieved in practice. Sufficient scientific data for a reliable assessment of the environmental impacts are still lacking. The available investigations are mainly short-term field tests or model calculations, the results of which cannot be generalised due to the very different test conditions.

Moreover, conflicts of objectives might occur in individual fields of application. In the case of weed control,

Drones: The possibility of attaching various sensor systems (digital cameras, multispectral and hyperspectral sensors), navigation and radio systems or smaller loads to a drone opens up a wide variety of agricultural uses. So far, in agriculture, drones have been used almost exclusively for crop cultivation. Here, a wide range of potential uses can be observed, particularly in the field of vegetation monitoring, locating wildlife animals and recording damage caused by wildlife animals, as well as in pest and weed control. Fields of application already established in practice are the detection of fawns using true-colour and thermal imaging cameras as well as the biological control of the European corn borer through the deployment of Trichogramma ichneumon wasps (fig. 2). At present, the potential applications of drones in agriculture are still restricted by their limited flight and carrying capabilities and the relatively high legal barriers regarding their use. Moreover, the analysis of the generated image data is very complex and usually not possible in real time, which is a disadvantage compared to ground-based sensor systems. Generating and interpreting the data requires the corresponding know-how. Hence, agricultural drone services are mainly offered by specialised companies.

In agriculture, **robots** have so far been used primarily in livestock farming to automate labour-intensive routine work in the barn. Automatic milking systems, automatic feeders and cleaning robots are fully developed and widely used. In contrast, robotic solutions for the complete automation of crop cultivation processes (sowing, fertilisation, pest management, weed control, harvesting, etc.) are still largely in the research and development phase. This is due to the high requirements for sensor data acquisition as well as the autonomous operation of machines in varying environments and conditions. Nevertheless, numerous concepts are being worked on in the area of field robotics, and first prototypes are available in fields of application such as weed control, sowing or vegetable and fruit harvesting. While further deployment of robotic solutions in livestock farming is essentially limited by the farm size required (for economical use), arable farming requires a fundamental reorientation of arable farming processes and crop cultivation systems – in addition to the need for technological development. In this context, for example, the opportunities of a very small-scale field management – which in future might even be oriented towards every individual plant – using small autonomous machines (spot farming) are being discussed. New machine concepts, such as units operating in a swarm (fig. 3), offer interesting perspectives in this context.

Fig. 2 Drone during the deployment of ichneumon wasps to fight corn borers

Outlook: potentials for a more sustainable agriculture

The digitisation of agriculture opens up a broad field of innovation that encompasses very different areas of technology, such as sensor technology, robotics, automation and artificial intelligence (AI). In fact, the greatest potential for optimising agricultural processes is seen in the comprehensive networking of these applications at farm level, which is far from being realised (for the prerequisites and implications of this vision, see TAB-Fokus no. 32). Nevertheless, available digital technologies already offer opportunities to make

for example, online procedures that carry out targeted chemical or mechanical control of identified individual weed plants significantly reduce the ecotoxicological effects compared to the hitherto mostly preventive application of herbicides. However, they allow very little or no residual weed, which in turn is very important as food supply and habitats for insects and birds. Potential environmental benefits due to digital agricultural technologies must therefore be assessed in the light of systemic interrelations. Rebound effects are also relevant. Thus, for example, the more efficient use of a resource, e. g. water for site-specific irrigation, can lead to a relative reduction in costs and ultimately, as a consequence, to an increased demand for this resource.

Through further technical development and networking, enhanced beneficial environmental effects can be expected in the future. At the same time, digital agricultural technologies alone appear to be not sufficient, or in some cases not suitable, to address some major environmental and animal welfare issues in agricultural production, e. g. overfertilisation as a consequence of intensive livestock farming.

agriculture more cost-effective and sustainable. However, a merely technology-driven innovation of agricultural production oriented towards increasing efficiency is probably not sufficient. At present, the trend towards the development of ever larger machines and high-tech solutions – which has characterised agriculture for many decades already – seems to be unbroken. In principle, the environmental impacts of precision farming are determined by a wide range of factors and are therefore difficult to assess (see box).

To ensure that further progress will lead to a more sustainable agriculture, research and development programmes are needed that are more closely aligned with agro-ecological principles than has been the case so far. With regard to more environmentally friendly farming, autonomous robots in particular open up perspectives for replacing large agricultural machines with many smaller units (some of which are swarm-based) that operate in a largely autonomous way and can be used around the clock. The ecological advantages of such small autonomous devices are reduced soil compaction and, above all, new opportunities for a very small-scale agricultural crop management – which in future might even be oriented towards every individual plant. Organic farming, which cannot resort to synthetic chemical pesticides and fertilisers, would particularly benefit from these devices. Furthermore, many approaches of organic farming (mechanical weed control, crop rotation) might be transferred to conventional farming by the use of autonomous small-scale technology.

However, such developments are still at an early stage, and there are still many research issues to be dealt with, e. g. how small machines operating in a swarm can contribute to a more sustainable agricultural production. This is not just about technical progress in the narrow sense, but about a holistic renewal of agricultural production systems around the new technologies. It would be desirable for innovation efforts in digital technologies to be more closely linked to other intended changes in arable farming (e. g. expansion of the crop spectrum and crop rotations). A tangible contribution to more sustainable farming cannot be expected until innovations are coordinated and complementary.

Fig. 3 »Xaver« by Fendt: robot units operating in a swarm

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Digitalisierung der Landwirtschaft: technologischer Stand und Perspektiven

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