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The contribution of Horticulture 4.0 innovations to more sustainable horticulture

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Abstract

Robotics, artificial intelligence (AI) and sensor-based solutions offer the opportunity to meet the current challenges in horticulture. To accelerate the integration of these technologies in the horticultural sector, the German Ministry of Agriculture established the funding priority Horticulture 4.0. Twelve research and development (R&D) and a networking and transfer project are funded to ensure international competitiveness and increase sustainability. This paper focuses on potential digital applications to be implemented in horticultural farms and analyses the technologies at the meta level by literature review and qualitative research. First, the 4.0 technologies based in the R&D projects are classified according to Industry 4.0 visions and systemized by degree of digital assistance. Six projects focus on a complete automation of production steps in horticulture, four of them on intelligent pest management. Thus, a use case "Digital insect trap" was established with automated detection and counting of insect pests and a digital assistance system for pest management. The results of these analyses provide a basis for future research on technology assessment. The impacts of this use case on sustainability of horticultural production are identified. There are various technical and economic effects on farm management, e.g. investment costs, reduced working time, live pest monitoring without delay and pest management on a broader data base. Less use of pesticides and more biodiversity in field and orchard cultivation are identified as potential ecologic effects. There are no indications that the employment in horticultural farms is affected, but the safety of employee's work place when using autonomous systems could be identified as social effects.

Keywords: Horticulture; innovations; technology assessment; qualitative research; sustainability

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1. Introduction

Digitization and automation offer great opportunities for horticulture. Robotics, innovative sensor-controlled solutions, data management systems and artificial intelligence can increasingly fulfill complex tasks in the control and management of production systems and help to make horticultural production more competitive and sustainable. Thus, digital methods are essential for horticultural production [1], their development and use are still in the early stages of development. To accelerate the integration of these 4.0 technologies in horticulture production, the German Ministry of Agriculture has established the funding priority Horticulture 4.0. Since 2019, twelve research and development (R&D) projects and a networking and transfer project are supported to develop and promote digital innovations for the German horticultural sector.

Industry 4.0 is useful for agriculture, but it has to be adapted [2]. Compared with Industry 4.0 developments that are based on standardized processes, Agriculture 4.0 technologies have to cope with a high degree of complexity, because there are a large number of variable factors influencing the process, e.g. site-specific information on soil properties and type of terrain, heterogeneous plant populations and uncertain weather conditions. In addition, Horticulture 4.0 is characterized by a great variety of horticultural crops as vegetables and fruits, ornamental plants, trees and shrubs. Therefore, development and use of 4.0 technologies in horticulture focus currently on individual solutions. Currently, a number of innovative prototypes for harvesting, robots for weed control and forecasting models for crop control exists. Yet the introduction of 4.0 technologies in horticulture is significantly more advanced in the field of sensors [3].

This paper aims to introduce the German funding priority Horticulture 4.0 and to present first results of the accompanying research on potential digital applications in horticulture that can provide a basis for future research on technology assessment. Section 2 is about the funding priority Horticulture 4.0 and the objectives of this investigation. Section 3 focusses on the methodological background. The results of this investigation are presented in section 4 and focus on the technology assessment by analyzing and systemizing of smart technologies under development in the R&D projects. From this, a use case “digital insect traps” is derived and its impacts on sustainability of horticultural production are elaborated. An outlook on future work is given in section 5.

2. Objectives and tasks of the funding priority Horticulture 4.0

The funding priority Horticulture 4.0 is based on the results of the research project "HortInnova - Research Strategy for Innovations in Horticulture" that emerged on a participatory process with a broad participation of sector stakeholders. Scientists, experts of horticultural enterprises and stakeholders of upstream and downstream industries discussed intensively in a series of workshops about innovations and research efforts needed for the horticultural sector that were transformed into a coherent research strategy. Horticulture 4.0 was identified as one of five research priorities with great impact on the competitiveness of horticulture and for achieving sustainability goals [4]. Thus, the German Federal Ministry of Food and Agriculture established this funding priority to explore smart technologies, e.g. to control processes and production systems in horticulture. Twelve R&D projects and the networking and transfer project HortiCo 4.0 are funded since the end of 2019.

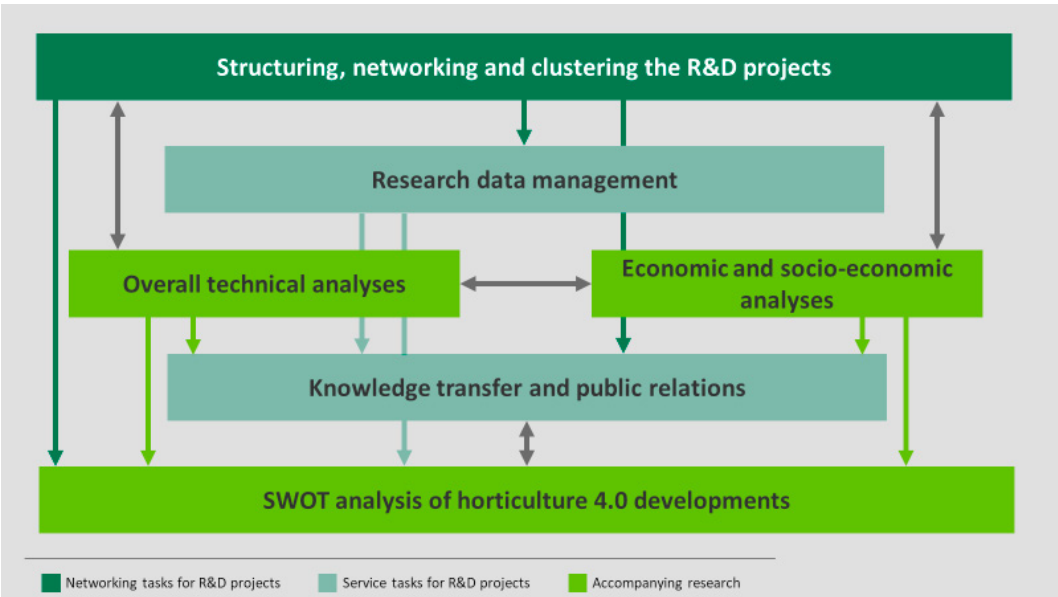
The R&D projects focus on supporting, simplifying or even replacing selected steps in vegetable and fruit growing, in ornamental plant production and in tree nurseries by digital processes. The research themes range from technology development, e.g. the development of robots, to new applications for existing hardware, e.g. sensors or drones, to machine learning methods or linked data concepts for automated data retrieval (cf. Table 1). The R&D projects are carried out by universities, universities of applied sciences, research institutes, industry and horticultural businesses.

The networking and transfer project HortiCo 4.0 aims to contribute to a wide dissemination of these smart technologies in the horticultural sector and to promote their acceptance by the general public. For this, scientific analyses and networking activities are essential. The different tasks and their interrelations are illustrated in figure 1. HortiCo 4.0 interlinks the Horticulture 4.0 R&D projects and identifies and leverages synergies between the different R&D projects. For this, innovation clusters are identified and cooperation between researchers of different projects is established and supported. Furthermore, HortiCo 4.0 supports the R&D projects in establishing an efficient research data management and is also responsible for knowledge transfer and public relations [5].

Table 1: The R&D projects of the German funding priority Horticulture 4.0

Acronym	Research and development project
Apfel4NULL	Sensor applications for sustainable apple production and storage
FlyingData	Use of autonomous drones for sustainable plant production in greenhouses
GeoSenSys	Georeferenced sensor-based data management system for site-specific irrigation and fertilization of open field vegetables
HortiSem	Aggregation of information for pest control in horticulture
IPMaide	Sensor based monitoring and decision support for integrated pest management for greenhouse crops
LichtFalle	A mobile LED-laser-trap to rouse, attract, monitor, and selectively control herbivorous insects
MiteSens	UAV based monitoring system for spider mites in greenhouse cultivation
PHLIP	Development of a smart 4D insect monitoring system for integrated pest control in commercial fruit growing
PlantGrid	Digital management support systems for small and medium-sized enterprises in value chains of ornamental plants, perennials and cut flowers
PlantSens II	Development of a multi-sensor system for the evaluation of the health condition of plants in horticulture including a control system for an automated crop protection agent application based on the analysis of digital imagery and short-range photogrammetry
RoBoKI	Plant Tissue Culture 4.0 - Artificially intelligent, fully automated in vitro plant production
WeBaRo	Christmas tree robot. Autonomous robot platform for planting, cultivation and long-term mapping of Christmas tree crops

Source: [6], own illustration.



Source: Own illustration.

Figure 1. Tasks of the networking and transfer project HortiCo 4.0.

At the meta level, HortiCo 4.0 will carry out impact analyses of the innovations under development. This research focuses on the analysis of technological potentials and the economic and socio-economic assessments of Horticulture 4.0 innovations with respect to their implications to the horticultural sector:

Overall technical analyses

Innovations are of great importance for the competitiveness of German horticulture. Thus, HortiCo 4.0 analyzes the digitization technologies with origin in industrial production and suitable for horticulture and assesses their importance for the sector. The expected technical progress and results of the innovation clusters will be examined with regard to their benefits and their impact on horticultural production processes.

Economic and socio-economic analyses

Economic analyses of the new technologies from the R&D projects will demonstrate how digital change affects the structure, competitiveness, and sustainability of the horticultural sector. They will take into account and evaluate both the effects at individual farm level, for example on the costs, profitability and efficiency of production systems, and the effects on the horticultural sector, i.e. farm structures and value chains. Technology assessments will address the potential of innovation clusters and their impact on individual enterprises, the horticultural sector, and society.

General technical and economic/socio-economic analyses interact with the projekt's structuring and networking tasks so that there are many overlaps to be found between them. In addition, knowledge transfer and public relations also benefit from these thematic analyses.

SWOT analysis

Finally, recommendations for policy-making, professional associations and actors along the horticultural value chains can be derived. Therefore, the strengths and weaknesses of digitization and its opportunities and threats for horticulture have to be identified and evaluated. This will be done from a technical and economic perspective and will be based on the results of all research work in the project.

The Thünen Institute, the Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB), the Service Center for the Rural Area (DLR) Rheinpfalz, the State Horticultural College and Research Institute (LVG) Heidelberg and the Institute of Mobile Machines and Commercial Vehicles at the Technische Universität Braunschweig are responsible for the scientific, networking and public relations tasks of HortiCo 4.0.

In this paper, first results on the technology assessment of innovations developed by the R&D projects in the Horticulture 4.0 funding priority are presented. Initially, the 4.0 technologies based in the R&D projects are classified according to Industry 4.0 visions and systemized by degree of digital assistance. Subsequently, a use case to pest control and management and its impacts on sustainability of horticultural production is presented.

3. Methodological background

The investigation is based on a technology induced assessment of innovations according to Renn [7] that means the technology assessed is already available, ready for production, or under development. In the sense of constructive technology assessment, a feedback of technology assessment into R&D is possible [8]. This is in line with the objectives of HortiCo 4.0: to assess comprehensively the 4.0 technologies to be developed in the R&D projects of the funding priority.

Technology assessment examines both desirable and undesirable effects of digital technologies. Therefore, the following steps guide the analysis:

- Classification of 4.0 technologies to identify technological priorities and potential practical use in horticultural farms and the sector. Therefore, fundamental developments of the Industry 4.0 or Horticulture 4.0 vision are outlined.
- Identification of technical and socio-economic effects of these technologies to capture the internal and external impacts of digital technologies, e.g. demand for (seasonal) labour or sustainability.
- Overall assessment of technology impacts to horticultural practice, value chain and society, e.g. customer.
- Economic analysis of costs, benefits, and profitability of selected digital technologies to evaluate the effects of the new technology on the competitiveness of the horticultural sector.

The data base for these analyses comprises literature analysis, an expert survey and focus group discussions:

Literature analysis

An extensive literature analysis and internet research focuses (1) on the developments and the use of 4.0 technologies in horticulture and (2) on already developed digital technologies such as prototypes or market-ready products outside of the Horticulture 4.0 funding priority. The digital technologies used in the R&D projects are systemized and grouped according to the basic concepts from literature on Industry 4.0. In addition, the literature contributes to identifying potential actors affected by digitization in horticulture and to ascertain possible effects.

Expert survey

With the help of an expert survey, technical details and social effects of digital developments in horticulture are examined. Therefore, guideline-based interviews with selected experts from the R&D projects are conducted. The developed guideline encompasses technological details as well as effects and prerequisites of the technologies. The interviews are organized as online meetings, of approximately 60 to 90 minutes.

The results presented in this article are based on the initial three interviews with experts from the R&D projects focusing on horticultural technology [1], mechanical engineering [2], and agricultural technology [3]. The qualitative data obtained are transcribed verbatim and translated into standard written German. The transcript provides the basis for an initial systematization of the collected data and an identification of key categories.

Focus group discussions

The results of the expert survey will be presented to and discussed with participants of focus groups. Thus, the results will be supplemented and adapted by focus group discussions. Through this, the results of the expert survey will be validated and put on a more general and abstract level.

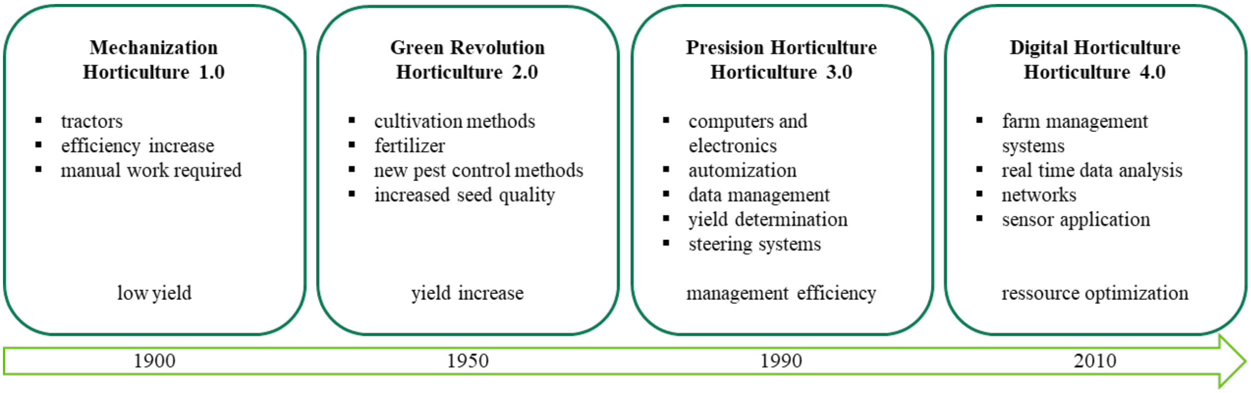
This methodological approach of gaining knowledge based on qualitative research, is considered by Bitsch [9] to be an important contribution to realistic research in agricultural and horticultural economics and is confirmed by current adoption research to digital solutions in agriculture [10].

4. Results to technology assessment for Horticulture 4.0 innovations

4.1. The development of Horticulture 1.0 to Horticulture 4.0

Comparable to developments in industry, technological developments in horticulture shown in Figure 2 can be classified into four main periods: The launch of tractors initiated the era of mechanization (Horticulture 1.0) which led to higher productivity in fruit and vegetable growing. The Green Revolution (Horticulture 2.0) stands for the use of high-yielding varieties of seeds, chemical fertilizers and pesticides and is characterized by drastically increasing yield levels. In the period of precision horticulture (Horticulture 3.0) computers and electronics allowed for higher efficiency in farm management. Current developments in digital horticulture (Horticulture 4.0), e.g. sensor applications and real-time data analyses, focus on optimizing resources [11].

The developments shown towards Horticulture 4.0 are not exclusive to it. The industry can be taken as a further example of a fundamental change in a sector, and here in particular with its term "Industry 4.0". This is less a description of an actual state, but rather a vision of future production [12-14]. Accordingly, the future industrial production is no longer characterized by monolithic systems [13, 15-17]. It will be a digitized, optimized and individualized production based on automated processes, human-machine and machine-machine interactions, including automatic data exchange - the understanding of the term "Industry 4.0" assumed in this paper [18-20]. The technologies and ideas fundamentally required for this transformation also enable the step towards Horticulture 4.0. The adaptation is obvious, since from a simplified perspective the field can be understood as a factory, the plant as a product and the machines as production facilities.

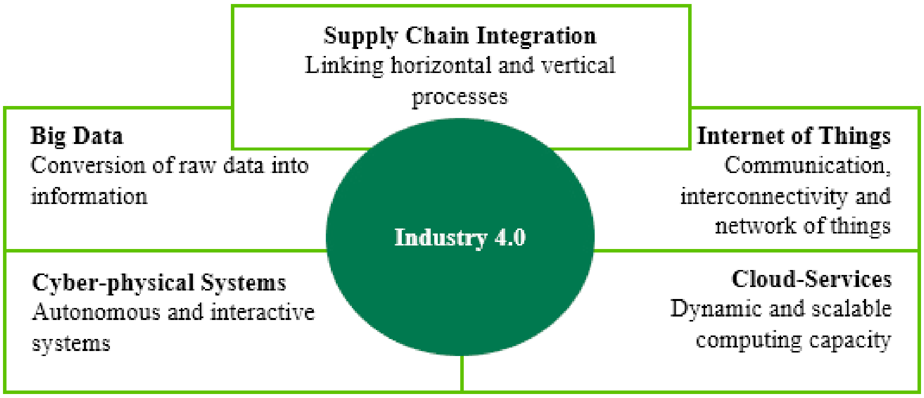


Source: [11], own illustration.

Figure 2. Main developments in horticulture – from Horticulture 1.0 to Horticulture 4.0.

4.2. 4.0 technologies in R&D projects

The R&D projects of the Horticulture 4.0 funding priority focus on very different research objectives and use different technologies as well. Following the approach of Beier et al. [14], Bär et al. [21] and Brozzi et al. [22], five technology areas have been identified: cyber-physical systems (CPS), cloud services, Big Data technologies, Internet of Things (IoT), and supply chain integration (cf. Figure 3).



Source: Own illustration.

Figure 3. Identified main Industry 4.0 technologies and fields of developments.

Cyber-physical Systems (CPS)

The CPS are characterized by the networking and interaction of the machines, with the inventories and operating resources used e.g. in a factory. These components communicate independently with each other and perform self-directed actions after changes in their environment - humans are no longer necessarily involved [23]. As can be seen from the explanations of the next technology fields, CPS are difficult to imagine without the aid of cloud services, Big Data technologies and the IoT. Nevertheless, CPS are essential as a fundamental technology field in the further consideration of technology impacts, as they represent an important element in the concept of Industry 4.0 [13, 17].

Cloud-Services

In this context, cloud services are primarily understood as cloud computing. The principle behind this concept is the shared use of the same computer resources by several participants. A connection to the Internet is required so that the corresponding resources can be accessed. The principle can further be divided into three different forms: Software as a Service, Infrastructure as a Service and Platform as a Service. A more detailed overview is provided by Shah et al. [24].

Big Data Technologies

In the following, the term Big Data covers all processes and methods that can convert large amounts of (raw) data into usable information in real time [14]. This includes also data from different sources.

Internet of Things (IoT)

The IoT can be identified as another core element of Industry 4.0 technologies. This technology acts as a connecting network between the individual participants in the production process, such as machines, sensors and products - thus ensuring communication and interconnectivity. In addition, new possibilities for human-machine interaction are conceivable [14, 25-27].

Supply Chain Integration

The "Supply Chain Integration" cluster is a special case in this context, because it is less about a specific technology than about the resulting possibility of integrating horizontal processes across company boundaries - the supply chain is includable in real time. This is a novelty insofar as this form of integration seems to be much easier to implement with the previously mentioned technology clusters [13].

From the explanations it becomes clear why AI, for example, has not been considered. At least in the case of CPS and data processing (Big Data Technology), some form of AI is a basic prerequisite for their implementation. Their use, in turn, may be positively conditioned by the use of cloud services due to the computing resources available. AI is therefore difficult to distinguish from the clusters and ultimately represents a basis which, however, does not in itself enable the implementation of Industry 4.0.

It also becomes evident that some of the technologies build or depend on each other. CPSs require effective and functioning data processing (Big Data). In turn, forms of IoT are required for communication between the individual components of a CPS. Cloud services help to provide the necessary computing capacity in a scalable manner as required.

In relation to the HortiCo 4.0 project, these technology clusters help to classify the R&D projects on a technical level and to support the technology impact assessment.

According to the clusters presented, the projects LichtFalle, PHLIP, PlantSens II, MiteSens, FlyingData, WeBaRo and RoBoKI can be roughly assigned to CPS. All of the projects mentioned have in common that their goal is a physical system in any kind (cf. Table 1). More specifically, the focus of the PHLIP, PlantSens II, MiteSens and FlyingData projects is primarily on intelligent monitoring systems in combination with drones or insect traps. The drones and insect traps represent the physically acting system, which can operate automatically through a combination of Big Data algorithms, IoT and/or Cloud Services. This is expected to reduce farmer's workload, especially in terms of time, and to support decision-making, e.g. on the optimal date for application pesticides.

In contrast, both the WeBaRo and RoBoKI projects stand on their own; the aim of WeBaRo is to develop an automatic Christmas tree robot that can plant seedlings and take care of pest control, including fertilization. RoBoKI also aims to develop a robot, but unlike the WeBaRo project, it is stationary. The robot is to be enabled by the use of sensor technology and AI to process plant tissue into plants fully automatically until they are planted in the greenhouse. In addition to the physical system, both projects use Big Data technologies, e.g. to recognize plants and initiate appropriate actions.

As already explained, the Big Data, IoT and Cloud Services clusters are often closely interlinked. This also applies to the HortiSem, IPMaide, GeoSenSys and Apfel4NULL projects. For this reason, direct assignment to a single cluster is not expedient. While HortiSem is about developing a tool for horticulturists that provides practical information on plant cultivation via appropriate end devices and accordingly no sensor technology is developed, the goals of IPMaide and GeoSenSys are to develop suitable sensor technology. This should support the user in decision-making in pest control (IPMaide) or in irrigation (GeoSenSys).

In contrast to the previous projects, the Apfel4NULL project has the most comprehensive approach; the influencing factors along the entire internal value chain are recorded with the aid of a sensor network and incorporated into a forecast as a decision-making aid. The overall goal is a resource-efficient, site- and season-adapted apple production chain. Due to the lack of actuators, all four projects do not represent a CPS.

PlantGrid is directed at the potentials of supply chain integration. The focus is on optimizing ornamental plant cultivation, with regard to minimize the loss of already produced plants through coordination across the respective operational boundaries, e.g. horticulturist, supplier and seller. Digital forecasting and planning methods are used for this purpose. The assignment to this cluster is evident.

This initial description of the 4.0 technologies indicates that the R&D projects are positioned broadly in terms of technology and that aspects considered in industrial production are also relevant for horticulture cultivation. Based on this classification, the technical analysis will be further elaborated to support the technology assessment. In addition to the identified technological areas, the digital assistance of innovations developed in the R&D projects is important for later use in horticultural practice.

4.3. Systematization of R&D projects by digital assistance

The R&D projects in the Horticulture 4.0 funding priority can additionally be classified according to their degree of digital assistance [28]. Digital assistance, also called farmer digital expert assistant, describes the situational support of the user up to the complete automation of a production step [29, 30] and covers three levels:

1st level of digital assistance: Monitoring

This step covers the implementation of sensor-based fully automated monitoring systems in horticulture production, e.g. collecting data on pest infestation levels or soil moisture.

2nd level of digital assistance: Processing monitoring data

The monitoring data collected in the first level are processed in digital analysis systems and forecast models for decision support, e.g. to recommendations on execution or postponement of pest control or irrigation.

3rd level of digital assistance: Complete automation of production steps

R&D projects with the aim to completely automatize cultivation steps are working on e.g. fully automated in vitro plant production, autonomous irrigation and fertilization of open field vegetables, or intelligent pest management in greenhouses and apple orchards.

Ten R&D projects cover the first two steps towards digital assistance (monitoring and processing data) and six projects focus on the third level of complete automation. The main focus of research work is pest control: six projects focus on pest monitoring (1st and 2nd level) and four on intelligent pest management (3rd level).

For this reason, a use case “digital insect traps” is selected for the socio-economic analysis. It fulfills characteristics of the first and second level of digital assistance. The digital processing of pest monitoring data into recommendations for horticultural growers and consultants helps to achieve a sustainable crop production in open field and greenhouse environments.

4.4. Use case “Digital insect traps”

Before introducing the digital use case, the state-of-the-art solution for insect pest monitoring and management in horticulture should be described.

In contemporary horticultural production, insect pest monitoring is based on visual assessment by on- or off-farm experts of insect pests, e.g. using insect traps such as yellow sticky cards. Management decisions on the strategy of pest control, i.e. timing and frequency of pesticide applications, are based on farmers’ professional skills or frequently supported by agricultural consulting and information services.

The use case "digital insect traps" bundles the approaches of three R&D projects which aim at digitizing insect pest monitoring and management. Their research is aimed at fully automating the insect trapping and counting activities and at combining these activities with a decision support system (DSS). Thus, digital assistance systems for pest management will be created.

The use case is based on the transcripts of the interviews with experts from the R&D projects. An additional literature review allowed the detailed description of the use case that consists of three important steps (Table 2):

Automated detection of insect pests

The digitization of pest monitoring is aimed at pest insects in open fields and in greenhouses and is intended to replace manual and visual monitoring via trap systems, such as yellow sticky traps. There are two technologies of insect detection in development: an optical detection via digitized traps [31, 32] and an acoustic detection via microphone arrays [33].

Both approaches of insect detection can be combined with autonomously moving platforms that drive through the crop rows in a flexible manner. However, detection of insect pests without an autonomous platform at fixed points in the field or greenhouses is also possible.

Table 2. State-of-the-art solution vs. digital use case for pest control in horticulture.
(n=3 expert interviews)

Task step	State-of-the-art solution: **Manual pest control**	Use case: **"Digital insect traps"**
Detection	- Insect traps (e.g. yellow sticky cards) - Funnel traps	- Optical and acoustic detection - Combination with autonomous platforms possible
Counting	Monitoring in the crops: e.g. manual counting of insect pests on yellow sticky cards	Digital monitoring: image recognition via AI
Evaluation	Management decisions on pest control based on - professional skills or - agricultural consulting	Digital assistance system for pest management based on the linkage of - crop-specific information and - digital pest monitoring

Source: [27-29], own illustration.

Automated counting of insect pests

The next step focuses on the identification of pest pressure by counting of insect pests (and antagonists) that are identified in the first step. This counting of pest occurrence is based on imaging measurement systems and AI.

Furthermore, a spatial localization of insect detection by the autonomously moving platforms can be transferred into map systems and provide important information for site-specific control of insect pests. Thus, intelligent pest detection models are developed.

Digital assistance systems for pest management

In addition to the digitization of monitoring insect pests that will be realized in the first two steps, the farmers can be supported by a digital assistance system for decision-making on pest management.

The digital technologies under construction are designed modularly so that they can combine the detection and counting step with an evaluating pest management tool, e.g. with a mobile application to run on a mobile device such as a smart phone or tablet. This application - as an interface between the digital pest control DSS and the user - will be supplied with specific information from the digitized insect traps, the farm specific crops and general information about pest control. Thus, the DSS consists of information on the crop produced, on pest control products (use restrictions, application rates, etc.), and on pest organisms, e.g. type of pests and their damage thresholds [34].

The DSS provides farmers with a wide range of pest control information and field specific data in a user-friendly manner - location- and time-independent. Compared to traditional analog pest monitoring and pest management, digital DSS allows to save time and further improve pest management decisions because they are based on much broader information.

4.5. Impacts of the use case "Digital insect traps" on sustainability of horticultural production

Implementing these digital insect traps in horticultural practice would have different effects on sustainability. These effects are elaborated from the interviews. The results are described according to the three factors of sustainability: economy, environment and social (Table 3). The indices refer to the three experts interviewed. Similarly, in the text below additional information is marked with [1]-[3] according to the interviewees.

Table 3: Sustainability factors in the example of the use case "Digital insect traps" and possible effects.

Sustainability factor	Effects on	Interview examples
Economy	Investments	• The technology must become so cheap that it is used/can be afforded. [2+3]
	Working time	• Reduction of working time, as no recognition, counting, writing down and scraping off of pest insects is necessary. [1+2] • Farm managers can concentrate on other tasks that are more important. [3]
	Pest monitoring and management	• Live monitoring without delay is possible. [2] • Smaller and more accurate crop monitoring is possible due to mobile insect trap (monitoring of single plants). [1] • Monitoring the success of a pest control measure is also possible. [1] • Decision on pest control is supported by broader data base. [2]
	Agricultural consulting	• Consulting can be improved. [2] • Consulting access to information derived from management tools improves the forecast models. [1] • It requires agronomic expertise to make those decisions (based on digital monitoring). [3]
	Development industry	• “Learning“ new insects. [1] • Training may require adjustments to the hardware. [2] • This requires also training of the users. [2]
Environment	Biodiversity	• Biodiversity can be determined. [2] • The biological potential for antagonists can be identified. [1] • Ecological evaluation of commercial orchards by monitoring systems. [1]
	Use of pesticides	• For orchards, tree-specific application is possible. [1] • Savings potential in fruit growing depending on planting distances. [1] • To assess whether pest control applications can be postponed for a little longer. [1]
Social	Job market	• The human component cannot be replaced because so much experience plays a role. [2]
	Systems security	• If you have an autonomous platform that drives through the greenhouse - you're also concerned about safety. [2] • Legal security of data for decision support systems. [3]

Source: Own data.

Economic Sustainability

To establish digital technologies in horticultural practice, the investment needs to prove its economic viability. Individual studies to digital investments, e.g. to autonomous platforms such as field robots, show that labour costs can be reduced [35, 36]. Currently, it can be stated that the use case "Digital insect traps" eliminates the need for manual evaluation of yellow sticky traps which us time-consuming and has low efficiency [31]. Plant-specific crop monitoring allows a site-specific or tree-specific application of pest control products. For agricultural crops, Rajmis et al. [37] showed that a site-specific application may lead to cost savings compared to a conventional whole-field application. However, there is also the risk that the digitized insect detection will fail. Misdetected insect pests can lead to significant economic damage [2]. Because of this, detailed cost benefit analyses will be carried out in the next months.

Even with the "Digital insect traps", it remains the farmer's task to evaluate the monitoring data and to choose and schedule a suitable pest control action. The monitoring itself is improved by real-time observation of the population in smaller plant plots so that it is possible to detect the development of a pest insect population quickly and to monitor the effectiveness of pest control measures conducted immediately. This leads to better pest management decisions.

The horticultural advisory service benefits from the possibility to get access to pest monitoring data. Their forecast models can be based on a larger and site-specific database and the quality of their farm consultancy will be improved. Furthermore, productivity advances to be expected with digitization will give rise to new services or business models [38]. With the digital insect trap and its location-independent pest monitoring, the advisory service could offer a "full package" of pest monitoring and consultancy.

Environmental sustainability

Digital insect traps can contribute to biodiversity preservation by providing an ecological assessment of field and orchard cultivation. For example, information on the occurrence and development of various antagonists is available to promote beneficial insect-friendly pest management up to leave out completely chemical pest control applications.

By linking digitized monitoring and site-specific pest control, the use of pesticides can be reduced [37]. Combined with a plant-specific application of pesticides, the environment can be protected better and biodiversity in field and orchard cultivation can be increased.

Social sustainability

From the job perspective, there are no indications that the use of digital insect traps will change employment in horticultural farms [31]. The human expertise to evaluate monitoring results is still required. Contrarily, digitization will improve pest management decisions which depend on various crop and site-specific conditions.

Implementing new technologies into horticultural practice requires also complying with the legal framework, e.g. with respect to safety aspects for employees. In some cases the legal framework is still not compatible with technological developments, e.g. for autonomous systems. There is a growing need to revise regulations to enable innovations without compromising the safety of the work place.

5. Conclusions

In this paper, the results of the first use case "Digital insect traps" are described. The diversity of topics in the R&D projects allows for the analyses of further use cases for a comprehensive understanding of the effects of digitizing horticultural production. Therefore, innovative application of irrigation and fertilization management or crop monitoring and supervision - based on sensor technology and imaging measurement systems - and their contribution to sustainability of horticultural production will be analyzed. Savings of resources for fertilizers and water can be expected and further promote more sustainability in horticulture.

Future work will focus on the profitability of the use cases like Gaus et al. [35] analyzed for weeding in agriculture. A subsequent technology-induced evaluation [39] will focus on the production processes and working methods that have to be changed by implementing the use cases derived from the R&D projects from the funding priority Horticulture 4.0 in horticultural production.

The expert interviews already indicated that farmer' reluctance to digitize farm operations could be a challenge for adopting digital technologies in horticulture. To identify weaknesses and fallacies of digital technology developments, in the next research step focus groups with farmers and actors along the value chain will be conducted and critical factors for a wide acceptance be identified. This information is important for the development industry seeking to transform the prototypes into marketable products.

Furthermore, the use case disclosed that new technologies may not fit into current legal framework, like Finger et al. [40] analyzed for precision farming. For example, unclarified liability questions regarding the use of autonomous systems in open field production represent an obstacle to their implementation [35]. Thus, there is a need for policy-making to readjust the legal framework to make it suitable for digital innovations [41].

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