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# How and why we built our Smart Farm

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The Smart Farm of Bioeconomy Campus project (2021–2023) developed a unique hub of Smart Farming technology. The resulting Smart Farm aims to accelerate the adoption of smart technologies in farms according to the United Nations Sustainable Development Goals (SDGs). Therefore, at the Smart Farm, near-market technologies and services are tested, developed, and demonstrated. The aim is to remove barriers to their adoption and accelerate innovation in the sector, significantly increasing the benefits for farmers and the related agricultural industry. The foundation of the Smart Farm is based on processing various types of data. In the project, data was intensively collected from 16 hectares of test plots where barley was cultivated. Regular measurements were taken from the soil, crops, and from machinery and tractors equipped with ISOBUS technology. Measurements included the use of wireless soil sensors (20 units), drone imaging (RGB, multispectral, and thermal cameras), satellite images, and tractor telematics data. Additionally, the usability of the 5G signal in machine guidance was measured. Based on the collected data, precision farming was planned and implemented. Automated field navigation with headland automation was compared to traditional manual driving methods. Using GIS, maps such as profitability and energy consumption maps were generated from the data. The project developed a Farmer's Data Repository, through which a farmer can license their data to the desired destination via a data delivery service. The project also demonstrated the operation of such a system, compliant with EU data regulations, in collaboration with partner companies. A comprehensive project, the Finnish Future Farm (2023–2026), has begun based on the foundation of the Smart Farm, involving companies, educational and research organizations, farmers, and stakeholders. The project will build a digital twin of the physical Smart Farm, both of which will be utilized in R&D, experimentation, and education.

*Keywords*: Smart Farm, Precision Agriculture, Digital Twin, Education, Adoption

## Introduction

Technologies related to sustainable development in agriculture have existed for a long time, but their practical application has been slow (Haapala 2013). For example, technologies necessary for precision farming have been available since the 1990s (Haapala 1995), but only a few have been widely adopted (Anand et al. 2023). Precision farming technologies such as field navigation and yield mapping are the most utilized, but site-specific control of production inputs is relatively underutilized (Talero Sarmiento et al. 2022). Smart farming, which utilizes precision farming technologies and intensive data processing, has gained attention in recent years. However, the adoption of smart farming also faces new obstacles, such as poor data availability and practical challenges of fair data economy.

Failure to use technologies that promote sustainability leads to unrealized potential and unmet (SDG) goals. Additionally, in case of failure, the effort put into developing these technologies is wasted. Thus, promoting adoption is desirable and economically viable.

Overcoming this challenge requires actions to eliminate obstacles to the adoption of smart technologies. These barriers exist in various areas related to the acceptability of solutions (Nielsen 1993), not solely economic, which is often offered as an explanation for poor adoption (Haapala et al. 2006, Haapala and Pasila 2009).

In agriculture, the end users of innovations are primarily farmers, who are often conservative and cautious adopters of new technologies. Fundamental reasons are related to lacking trust and low level of willingness to risk-taking (Wielinga et al. 2017). New technology itself induces fear and uncertainty, leading to reluctance in investment. Decision making suffers from a lack of reliable and unbiased information regarding the effectiveness of alternative solutions.

The goal of the development project for the Smart Farm at the Bioeconomy Campus (2021–2023) was to establish a unique hub for smart agriculture technology expertise in Tarvaala, Saarijärvi, in Central Finland. The resulting Smart Farm would provide an opportunity to test, develop, and demonstrate near-market (TRL 7-) technologies and services. The aim was to remove barriers to their adoption and accelerate innovation in the sector, significantly increasing the benefits for farmers and the related agricultural industry. The project also aimed to lay the groundwork for a broader centre of expertise to be built after the project.

## Materials and methods

The construction of the Smart Farm began with needs definition. The starting point was the need for abundant high-quality data because Smart Farming ultimately relies on the generation and utilization of big data (Wolfert et al. 2017). The aim was to fine-tune the functionalities required at the Smart Farm using diverse types of essential data and to lay the groundwork for broader, adoption-promoting operations in the future, aligning with our vision.

Given that precision farming serves as a crucial technology for realizing the Sustainable Development Goals (SDGs), we prioritized the sensor data essential for its implementation, alongside the needed data generated by tractors and machinery. Additionally, the performance of data transmission was measured, as it will be a critical factor in the future with increasing automation.

During the growing seasons of 2022 and 2023, data was intensively collected from a total of approximately 16 hectares of test plots where barley was cultivated. Barley was chosen as the test crop as a typical cereal crop. Regular measurements were taken from the soil, crops, and from tractors and machinery equipped with ISOBUS technology.

Precision farming implementation and comparison to traditional farming methods were carried out in Huipuri test plot. Half of the plot was subjected to precision fertilization, while the other half was cultivated with a standard amount of fertilizer. The Maatalo plot was used as an experimental area (Fig. 1).


Fig. 1. Test Plots. On the left, a drainage map; on the right, the division of the Huipuri field for precision farming and traditional cultivation methods. The Maatalo plot was a test area where the functionality of the technology was evaluated.

Various measurement instruments were used in the test plots, including wireless soil sensors (20 units, Fig. 2), drone imaging (RGB, multispectral, and thermal cameras), soil scanning, satellite images, and tractor telematics data. Soil compaction was measured using positioned penetrometer measurements.

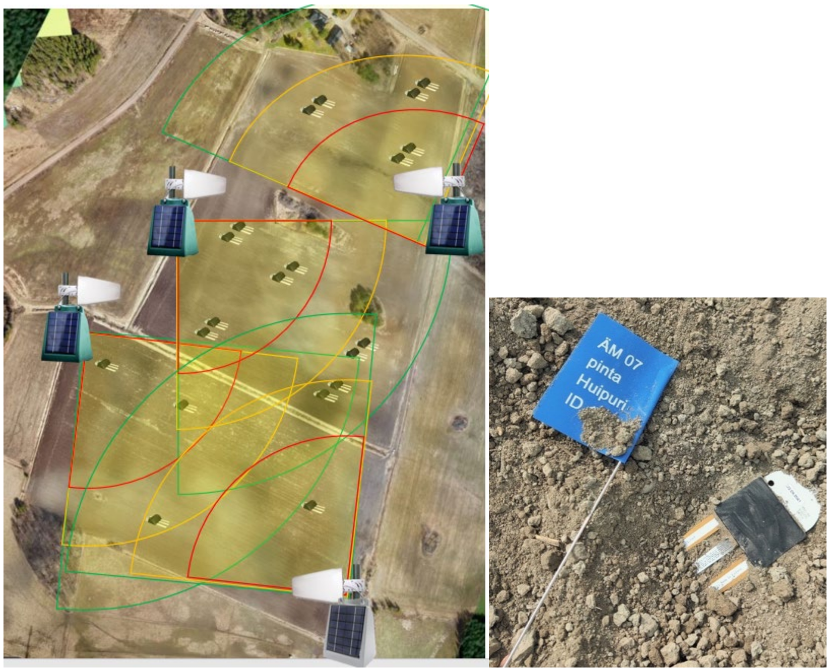


Fig. 2. Placement of wireless soil sensors in the experimental plots (left). The sensor and its labeling (right).

Wireless data transmission performance was studied in a case of using 5G signals in machine guidance.

Automated field navigation with headland automation was compared to traditional manual driving methods (Fig. 3). Using GIS, various maps such as profitability and energy consumption maps were generated from the data.

Fig. 3. Route map of the tractor during the sowing process. Automatic steering on the left, manual steering on the right.

In a data-driven smart agriculture system, data management is a key element. The farm's information system should be able to serve internal processes of the farm, e.g. FMIS, as well as external data users. To ensure that data is clearly in the farmer's possession and accessible to different users, it was decided to develop a specific Farmer's Data Warehouse, through which the farmer can license their data to the desired destination via a data intermediation service.

## Results

The results are related to the actual cultivation operations performed but especially to how various data types affect the implementation of a Smart Farm that promotes the adoption of SDG technologies.

Precision fertilization affected the yield obtained. Based on soil measurements (soil sensors, soil scanning, soil sampling, drone imaging etc.), the selected fertilizer levels were reflected in the following year's yield map, with a better yield level (green area) becoming more common in the precision-fertilized part of the Huipuri plot (Fig. 4).

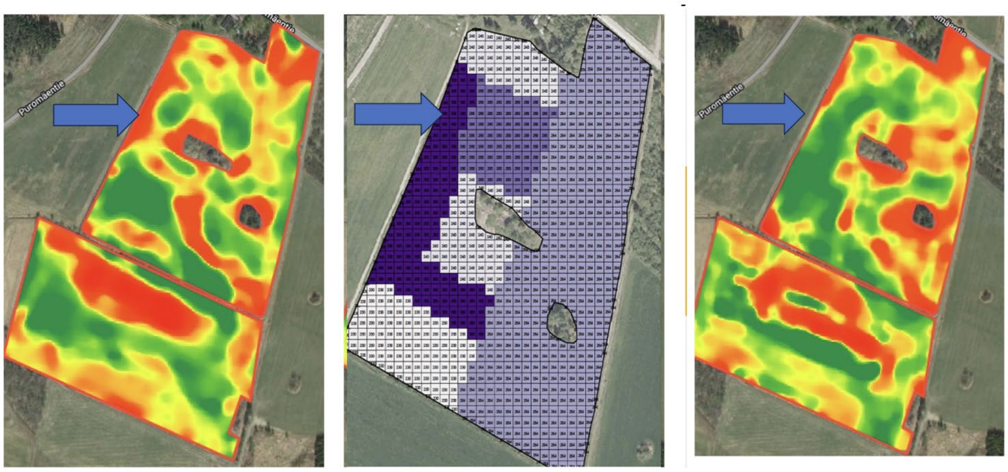

Fig. 4. Precision farming in the experimental plots in 2022 and 2023. On the left, the yield map for 2022; in the middle, the fertilization map for 2023; on the right, the yield map for 2023. The precision farming area (left side of the maps) is gaining in yield; the green area in the yield map.

The Farmer's Data Warehouse was implemented using example data from drone imaging and soil-sensor-produced soil data (Fig. 5).

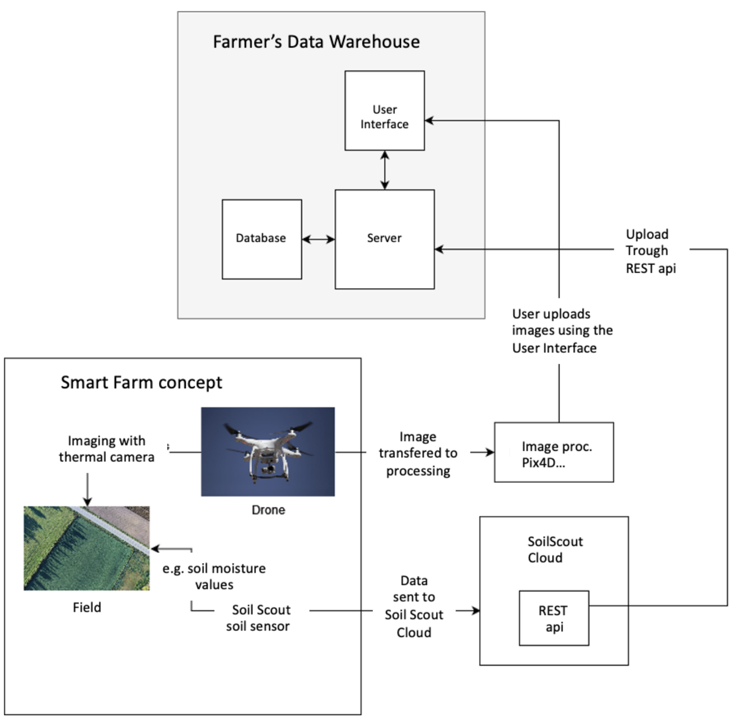


Fig. 5. Farmer's Data Warehouse, featuring drone images and soil data produced by soil sensors.

To test the fluency of data transfer between the Farmer's Data Warehouse and auxiliary systems, the operation of a novel data intermediating system compliant with the new EU data regulations was demonstrated in collaboration with partner companies (Dataspace Europe and Yield Systems).

In the 5G measurements, the signal coverage and usability were verified through field measurements and simulations. 5G measurements demonstrated that the tested measurement method, terminal devices, and measurement software were useful. Through test setups, the effects of buildings, forest canopy, and varying terrain elevations on the coverage of the 5G network signal were validated (Fig. 6).

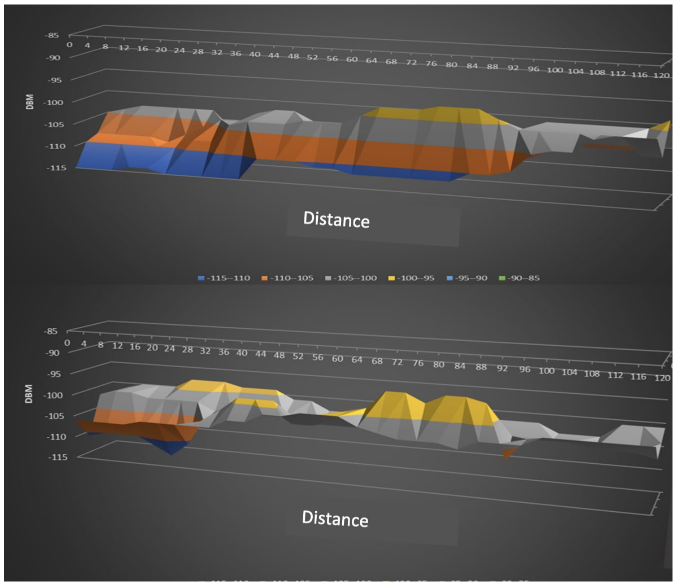


Fig. 6. Field strength values (dBm) in terrain measurements at sensor heights of 2 and 3.5 meters. The yellow color indicates best values.

Various economics maps were generated from the data using GIS software. All costs and income were calculated for defined grids, e.g. 10×10 metres. The data also included the work time spent in each grid point since it was available from the telemetry data of the tractor. (Figs. 7 and 8)

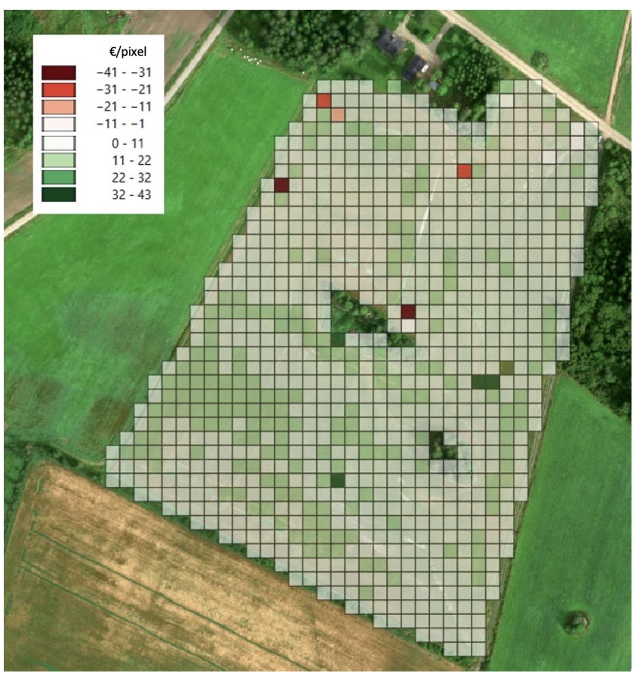


Fig. 7. Return map on a 10×10 meter grid

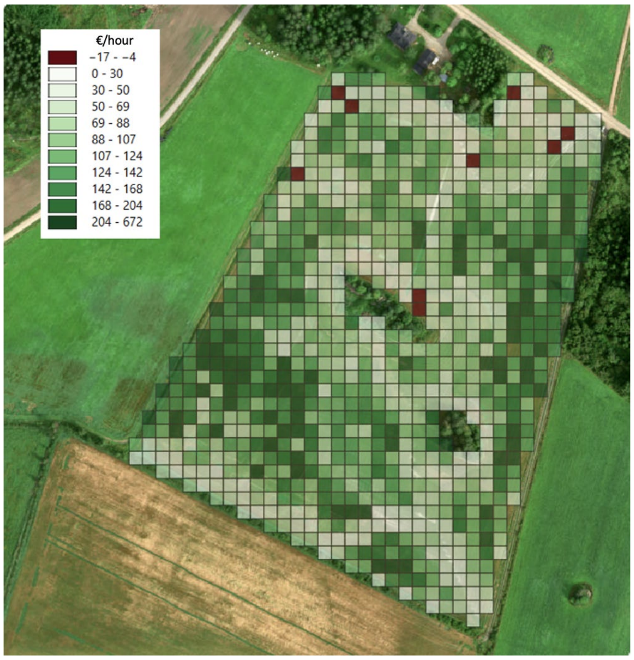


Fig. 8. Hourly wage map on a 10×10 meter grid

During the project, the Bioeconomy Campus Smart Farm joined the Nordic Testbed Network as the Smart Bioeconomy Testbed, which describes the nature of the operation as a genuine testing environment.

Feedback was gathered during the project. The main result was that a further development needed is a collaborative farm network. Based on feedback received along the project, there is interest among farmers in joining the network.

The project laid groundwork for the Finnish Future Farm project, commenced immediately after the project, involving a physical Smart Farm linked to a digital twin of the farm and extensive education and business acceleration sections (Fig. 9).

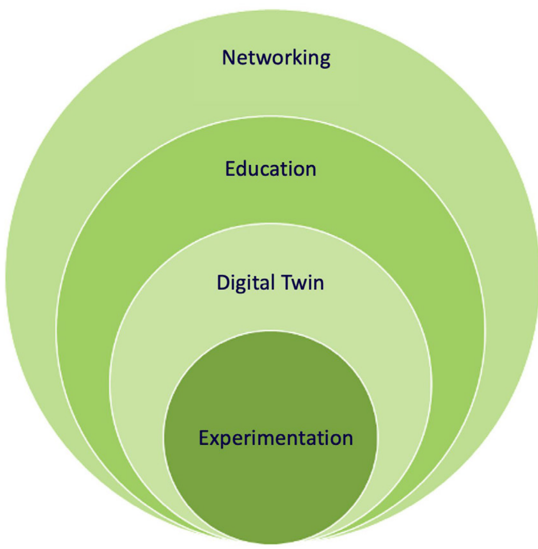


Fig. 9. Finnish Future Farm. The Smart Farm forms the foundation for experimentation upon which a virtual digital twin is created, along with an educational and networking component that utilizes them.

# Discussion

The main goal of the project, as stated earlier, was to lay ground for a Smart Farming competence hub that would accelerate the adoption of smart technologies in farms according to the United Nations Sustainable Development Goals (SDGs). This required understanding the types of data collected on a farm and how the Smart Farm could handle it. This goal was successfully addressed using the example data available. Tested data types, including e.g. sensor data, telemetry data, and drone imagery, were made available to the Smart Farm through the developed Farmer's Data Warehouse. Data transfer to external systems was achieved in various ways, including principles of fair data economy according to the forthcoming EU data regulations. This was demonstrated first time in Europe with an official data intermediation service (Tritom by Dataspace Europe Ltd). 5G data transmission was found to be challenging but functional in some cases which is in accordance with current research (Heikkilä et al. 2022).

Through intelligent data analysis, various metrics were derived from the Smart Farm's data, which could be presented in map format. These metrics can be used in the future to demonstrate and evaluate the benefits of SDG technologies. The economic maps of precision farming were the first ones reported in literature. These were done because economic benefits are a powerful way to affect the smart farming investments of farmers (Garcia et al. 2023)

The developed Smart Farm concept is international. The Nordic Testbed Network provides a good channel to experts in smart agriculture and other closely related smart technology application fields.

The concept is closely associated with R&D and education services, which will be offered in the form of a DIH (Digital Innovation Hub) in the future. DIH services were developed in a simultaneous EU-funded SAH project (SAH 2024), where Jamk laid the groundwork for defining the necessary services for various target groups.

# Conclusions

The core of the established Smart Farm concept lies in the physical Smart Farm with continuous comprehensive measurements and monitoring, allowing it to be used extensively for testing and further development of Smart Farming technologies and practices.

The farm network that is under construction enables real-life experimentation in a Living Lab style, providing insights into end-users' use-scenarios and requirements for new technologies.

The collaborative network is an integral part of the Smart Farm concept. Through collaboration, the Smart Farm has already been involved in other networks promoting agricultural data economy, leading to collaborative projects where the connection between the Smart Farm and the agricultural data space is tested and developed concretely together.

A comprehensive project, the Finnish Future Farm (2023–2026), has commenced based on the foundation of the physical Smart Farm, incorporating a digital twin of the farm. Both will be utilized for research, development, and innovation activities as well as education. Thus, the developed Smart Farm concept has contributed to the formation of an expertise hub that significantly improves the profitability and environmental friendliness of farms in the future. The commitment of companies to continue the project indicates that the project has succeeded in its main objectives.

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