Available online at www.sciencedirect.com
ScienceDirect
IFAC PapersOnLine 59-33 (2025) 13–18

Automation of Subsurface Drainage/Irrigation: Lessons from Field Experiments and Insights from Finnish Farmers

Pierre Jaouen * **Miika Läpikivi** **,*** **Maarit Liimatainen** **,***
Toni Liedes * **Enso Ikonen** *
* *Intelligent Machines and Systems, University of Oulu, FIN-90014 Oulu, Finland (e-mail: pierre.jaouen@oulu.fi)*
** *Natural Resources Institute Finland (Luke), FI-90570 Oulu, Finland*
*** *Water, Energy and Environmental Engineering, University of Oulu, FIN-90014 Oulu, Finland.*

Abstract: Automated drainage and irrigation in agriculture are discussed, based on experiences of an implemented model predictive control (MPC) in a pilot field, and a survey and interviews among the Finnish farmers on their water management practices. The experiments emphasized the importance of exploiting the extra time gained by using weather forecasts. The farmers' attitude to monitoring and control automation was found to be positive, with contributions expected in particular to increase yield and crop quality. The willingness to invest in automation for water management is impeded by the economic situation.

Keywords: Controlled drainage; Control in agriculture; Model Predictive Control; Interviews; Farmers' opinion; Subsurface drainage; Subsurface irrigation.

1. INTRODUCTION

The practice of agriculture is based on water management, with 70 % of freshwater withdrawals used for agriculture worldwide. The importance of water management in agriculture will be emphasized in the future due to climate change and water scarcity (Fyles and Madramootoo (2016)).

In Northern Ostrobothnia, Finland, typical challenges in water management are due to i) excess water and sometimes flooding due to snow melting in April-May, ii) potential drought periods in June-July and iii) excess water due to rainfall in autumn. The development of digital technologies offers farmers opportunities to tackle the abovementioned challenges (Parra-López et al. (2025)). Agriculture 5.0 further emphasizes the integration of these digital solutions taking into account human, environmental and social factors (Balaska et al. (2023)).

In Finland, where most of the fields are subsurface drained, controlled subsurface drainage has gained interest as an adaptive way to manage water (Salo et al. (2021)). For instance, control wells are installed between the drains and the outlet ditch. The wells are equipped with valves that the farmer manually closes or opens to regulate drainage and the depth of the water table. Automation of control wells allows for more frequent valve operations without manual intervention of the farmer and can have benefits on yield and smart water use while reducing farmers' workload. In addition, diminishing the depth of the water table could reduce the greenhouse gas emissions of cultivated peatlands (Evans et al. (2021)).

The remainder of this paper is structured as follows. Section 2 describes experiments with a model predictive control (MPC) automated drainage pilot. The main focus of the paper is on the survey and interviews among the farmers. In Section 3, the methodology for the interviews and the survey is detailed, and the results are presented in Section 4. Section 5 discusses the information gained for the further development of automated controlled subsurface drainage and irrigation systems.

2. AUTOMATED DRAINAGE PILOT

Subsurface drainage control experiments were carried out from June to October 2023 on the Kannus campus of the Federation of Education in Central Ostrobothnia (Kpedu), a 15 ha subsurface drained field (N 63°53, E 23°56). The upmost sector of 3 ha was used for the experiments. This sector contains drainage pipes leading to a control well. The system was instrumented with two water level sensors: one in the control well and a groundwater well at an 8 m distance from the control well. Measurements also included soil moisture (at 0.15 and 0.30 m below ground) and information on control latch position, battery voltage, and water temperature. A weather station, located in the middle of the field, provided hourly measurements of air temperature, humidity, wind speed, wind direction, and precipitation.

The control actuator (latch and motor) was installed in the existing well, together with the instrumentation, energy (solar panels and batteries), and communication systems. The on-site system communicates measurements and actuator control signals via mobile radio transmission with

10.1016/j.ifacol.2025.12.415

the cloud-based information system (thinger.io). Communication occurs every 30 minutes or every two hours during freezing to save battery energy. The actual MPC controller with the weather forecasts was implemented on a PC using Matlab at the University of Oulu. The control system can operate fully automatically once the user has defined a setpoint for the groundwater level through the web-based user interface (UI). The UI also displays continuously updated field measurements and controller-related signals, enabling remote monitoring.

A major goal for the control development was to be able to anticipate the future using weather forecasts. Therefore, a short-term field water balance simulation model was developed. The modeling method was similar to the one described in Ikonen et al. (2023) except that the recharge to groundwater was estimated as a proportion of precipitation minus evapotranspiration. The model consisted of a mass balance equation that included precipitation, estimated evapotranspiration, Hooghoudt's drainage equation for the flow from soil to subsurface pipes; and a tank model for the control well whose output flow rate was adjusted by the valve opening. After linearization and discretization, this resulted in a two-state linear system model:

$$\mathbf{x}(k+1) = \mathbf{A}\mathbf{x}(k) + \mathbf{B}\mathbf{u}(k) + \mathbf{d} + \mathbf{W}\mathbf{w}(k) \quad (1)$$

where state vector $\mathbf{x}$ consisted of the two water levels (control and groundwater well levels), the control vector $\mathbf{u}$ of the valve exit and irrigation flows, and the disturbances $\mathbf{w}$ of the forecasted precipitation and evapotranspiration. Matrices $\mathbf{A}$, $\mathbf{B}$, $\mathbf{d}$ and $\mathbf{W}$ contained the appropriate linearized model coefficients. 10-day forecasted precipitation was downloaded from the Finnish Meteorological Institute. Evapotranspiration was estimated based on hourly irradiation profile averaged over yearly data.

The goal of control was to follow the set point for the groundwater level, subject to constraints set by the physical limitations of the actuator and the geometry of the well. The MPC was designed based on the linear time-invariant model given by Eq. (1). The optimization problem was solved using linear programming (LP). The manipulated variable was the control well's valve opening percentage. The MPC prediction and control horizons were set to 9 days, with a 30-minute sampling interval.

2.1 Demonstration

A control system prototype was implemented at the test site in Spring 2023 and used from June 2023 to October 2023. During the early summer period (June-July), the groundwater setpoint was set at -0.14 m (i.e., 0.14 m below the surface) to prevent the crop from being damaged by drought. Hence, the first part of the growing season was used to test the controller implementation and infrastructure, while keeping the control valve closed (0 %). The early summer was very dry and the control well remained empty for extended periods of time. Since irrigation was not possible, the system was outside the controllable area and used for monitoring only.

The MPC was activated on August 30th by changing the setpoint from -0.14 to -0.84 m. This resulted in an immediate opening of the valve at 10 %, which led to the emptying of the control well in 20 hours (Fig. 1).

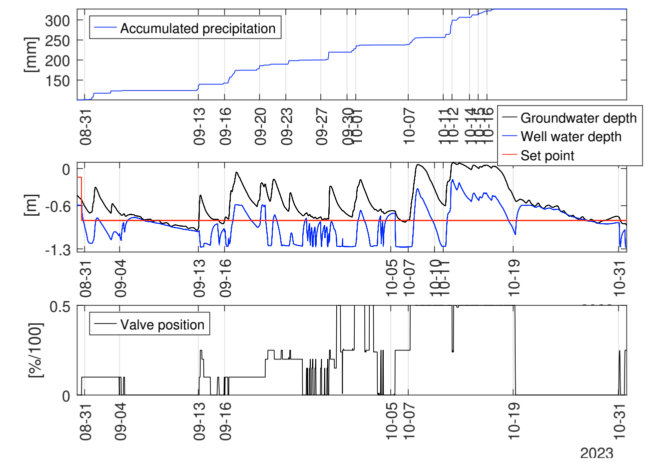

Fig. 1. Measurements at test site from end of August to October 2023.

The response of groundwater level was equally immediate, decreasing from -0.51 to -0.71 m. The MPC closed the valve on September 4th and the valve remained closed for 10 days, leading to equal levels in the control and groundwater wells. The groundwater level reached its set point on September 7th, that is, the MPC anticipated the lack of precipitation and closed the valve three days in advance despite being above the set point.

Toward the end of the term, the MPC closed the valve on October 19th. No rain was forecasted, the field slowly dried, and the groundwater level dropped. From the end of October, the air temperatures at the site fell below zero, i.e., precipitation was snowfall. As winter proceeded, ground frost separated the surface water system from the soil water system and groundwater, making the use of the MPC based on weather forecasts infeasible. Consequently, the controller was switched from the MPC to a simplified winter mode, which activated the valve at regular times. The system worked correctly in winter conditions.

Although the MPC controller was functional, groundwater level control was limited by the dimensions of the well and the reliability of the weather forecasts. For example, on October 7th the system was at the setpoint, the valve was 25 % open, and the control well was empty. Heavy rainfalls were predicted and anticipated by the MPC which opened the valve two days before they arrived. However, since the control well was empty, the actions did not have any impact. The subsurface system flooded and the water in the control well rose above the flood pipe level (-0.6 m). The water level then started to decrease, but due to past precipitations and heavy rains on the 11th, the water level rose again above the flood pipe level and stayed there for a few days. The control valve was fully open, but since the entire field was flooding, this had no impact.

The issue related to the reliability of the forecast prediction can be observed with a MPC prediction snapshot (Fig. 2). On September 7th, there was no rain forecasted for 5 days in sight, so the valve remained closed. The groundwater level was correctly forecasted. Some heavy rain was forecasted towards the end of the prediction horizon, one week ahead. However, the rain occurred more intensely and one day before forecasted. The valve remained

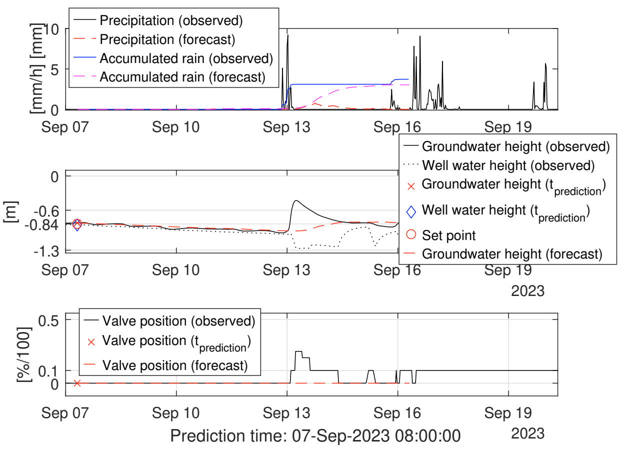

Fig. 2. Prediction snapshot at 07-Sep-2023 08:00. Groundwater depth and well water depth are near set point. The precipitation that occurred the 13th is not forecasted correctly so the predicted groundwater height is underestimated. The MPC only opens the valve when the rain occurs on the 13th.

closed in the optimized control sequence, as justified by the predicted values for the height of the groundwater table. Since the MPC did not correctly anticipate heavy rain, it only acted when the groundwater level rose above the setpoint (Fig. 1). Similar behavior was observed on the 16th of September: heavy rain was not correctly predicted and the groundwater table rose almost to the ground surface.

The results show that the system's control is heavily impacted by drainage constraints and uncertainties in weather forecasts. This emphasizes the importance of exploiting the extra time gained with forecasts and the proper evaluation of risks. For these aims, MPC is the proper control design paradigm for the problem.

MPC allows for a versatile setup of the cost function and constraints. It is therefore of interest to focus on the problem setting from the end-users' perspective. To achieve these goals, farmers' experience and opinions were collected through a digital survey and interviews.

3. METHODOLOGY FOR DATA COLLECTION

Data was collected using a mixed method approach, combining an online questionnaire survey and interviews with farmers. In total, 31 farmers, mostly from Northern Finland, responded to the questionnaire survey and 4 interviews were conducted.

3.1 Questionnaire survey

The objective of the survey was to gain an understanding of the current water management practices implemented by farmers and to gather their views on automation and monitoring for agricultural water management in terms of usefulness, attractiveness and potential benefits.

The term automation was defined to the farmers as the use of technology to reduce human intervention, including control systems that make decisions instead of the farmer. The closing and opening of well valves that can be automated (fully or partially) to control the drainage of a field was given as an illustrative example. The term monitoring referred to the observation of variables (soil moisture, water table height, temperature) via measuring devices to, for instance, support farmers in making informed decisions to increase productivity or minimize environmental impact.

The survey was anonymous and open from January 2025 to June 2025. The link to the survey was published in a vocational magazine, shared on social media, and included in several newsletters sent to farmers. However, most of the answers were obtained during visits to farms and agricultural events.

The questionnaire was divided into five sections:

(1) general information about the farm,
(2) current water management practices,
(3) control wells usage (respondents could skip this section if they did not possess control wells for subsurface drainage),
(4) monitoring and automation solutions for agricultural water management,
(5) final comments.

Most of the questions were attributed predefined multiple-choice responses with a free text option. Respondents were also asked to give their opinion on the benefits of automation and monitoring in agricultural water management for different purposes by using 5-point Likert-type answers. Two additional Likert-type questions asked about the interest of farmers to control groundwater level and soil moisture. Finally, two free text questions were posed: "Considering your situation now, what are the biggest challenges to invest in automated drainage systems?" and the optional comment from the farmer at the end of the survey.

3.2 Interviews and visits to farms

Qualitative interviews were conducted with farmers who have control wells for subsurface drainage. The farmers selected as interviewees prioritized agricultural water management differently. In addition, farmers' views were gathered through discussions with a researcher from Natural Resources Institute Finland (Luke) who has been interacting with farmers for several years.

Open-ended questions were prepared to guide the interview, but the discussion was kept open and the interviewees were free to lead the discussion and give their comments. This format was chosen in order to allow the interviewees to share their experience, opinions, and ideas. Indeed, qualitative interviews are a relevant method for capturing the points of view of participants and uncovering innovative ideas (Lillestrøm et al. (2024)).

The interviews were conducted in April and May 2025 at the farmer's location or remotely. The fields were dry at this time, so a visit to the fields and presentations of the water management systems implemented were possible.

The interviewees were briefed about the study purposes and how the data would be used. Questions were asked to:

(1) understand how the farmers are using the control wells and how satisfied they are with them,
(2) grasp what the farmers' needs are in terms of control, what variables they are interested to control, and in what way; and
(3) understand the relevant monitoring needs.

All interviewees also answered the online survey. The interviewees were given anonymity and are identified by their code F1, F2, F3, and F4 in the remainder of this paper.

4. RESULTS

4.1 Current water management practices

All the survey respondents, but one, had been doing some water management during the last five years. The most common reasons for implementing water management practices were preventing the fields from getting too wet ($n = 28$), improving growth conditions ($n = 27$), and increasing yield ($n = 25$). Among the listed water management methods (Ditch drainage, Controlled drainage, Traditional subsurface drainage, Two-level channel, Submerged weir, Surface irrigation, Subsurface irrigation, Constructed wetlands, Paludiculture, Water reservoir), subsurface drainage ($n = 24$) and ditch drainage ($n = 18$) were the methods most commonly used. 29 respondents were draining their fields in one way or another. These results confirm the predominant importance of drainage in Finland. Only 3 respondents used surface irrigation, but a more important part ($n = 8$) used subsurface irrigation.

Approximately two thirds of the respondents answered that they were using several water management methods. This is consistent with an interviewee's comment stating that each field has its own particularities and therefore its own water management system (F2). The configuration of the fields can also impact how water management is conducted, as stated by F2 who reported keeping control well's valve open during the winter to avoid risk of sudden flood which would prevent accessing the well. Farmers are also updating and modifying existing drainage systems in their fields.

Most of the respondents answered that they measured precipitation ($n = 24$), but only a few of them measured soil moisture ($n = 8$) or groundwater height ($n = 9$). However, measuring a variable did not mean that it was analyzed further. Even if groundwater level was said to be measured, measurement could be done via the well level, which only gave an approximation of the groundwater level in the field. Furthermore, groundwater level measurements were often rare (once or twice per year). The researcher from Luke confirmed that groundwater levels were almost never measured by farmers, while soil moisture was measured by some of them. For instance, F2 reported measuring soil moisture to decide when to start pumping water from the nearby river for irrigation.

22 respondents answered the questions related to control wells for subsurface drainage. The main reasons for having control wells were increasing crop yields ($n = 20$), preventing drought damage ($n = 18$), and improving crop quality ($n = 16$). In addition, 16 respondents wrote that they had access to a water source for subsurface irrigation and 12 of them had considered or were already using their controlled subsurface drainage system for subsurface irrigation.

Most of the farmers who had control wells used them actively, that is, more than twice a year. F1 kept track of valve operations and recorded in a diary the reasons for closing or opening the valves. Only four farmers responded that the valves were always open, and two were only opening the valves in fall, and closing them in spring. Others operated the valves more than twice a year. This was most commonly done throughout the growing season to optimize the growth condition or based on weather forecasts. Four respondents were opening the valves before doing work on the fields. Manual and regular operation of valves was, thus, already practiced in several forms, which means that there was an understanding of the benefits of frequent operation of the valves, and automation of their operations can make sense. Frequent management of the drainage level (here through control wells) can optimize groundwater levels and therefore improve the efficacy of controlled drainage (van de Craats et al. (2021)).

4.2 Automation, monitoring and forecasting

Most of the respondents would agree to let an automated system control the valve in the control well for them, at least after tests in their fields. This result confirms that an automated system such as the one presented in Section 2 is relevant to farmers. They also generally agreed on the benefits of automation for agricultural water management. For example, automation of control wells would be relevant for F3, as they regularly open and close the valves before important rain events. F4 also agreed on the benefits of automation since it took half a day to close or open the valves of the control wells in their fields, which was not always done at the right time due to other farm works having higher priority. The respondents to the survey answered that automation could be mostly beneficial to increase yield. More than half of them responded that automation could be beneficial in improving crop quality, making life easier, or using water more efficiently. Automation was deemed less beneficial for minimizing environmental effects (Fig. 3).

From the discussions, it appeared that the farmers relied primarily on their experience with their own fields and observations rather than on water-related measurements. However, some farmers used monitoring of weather or water-related variables for scheduling of work. F1, who used a digital service to follow weather variables, mentioned that it could be advantageous to have some artificial intelligence (AI) for decision making based on weather observations and measurements in the fields. Whether AI or not, a predictive model such as the one mentioned in Section 2 answers this need. F3 regularly monitored their fields with a drone to understand where water management needed to be improved. According to the results of the survey, the monitoring in agricultural water management was perceived to be most beneficial in increasing crop yields. It was considered less beneficial to develop farm operations based on collected data (Fig. 4).

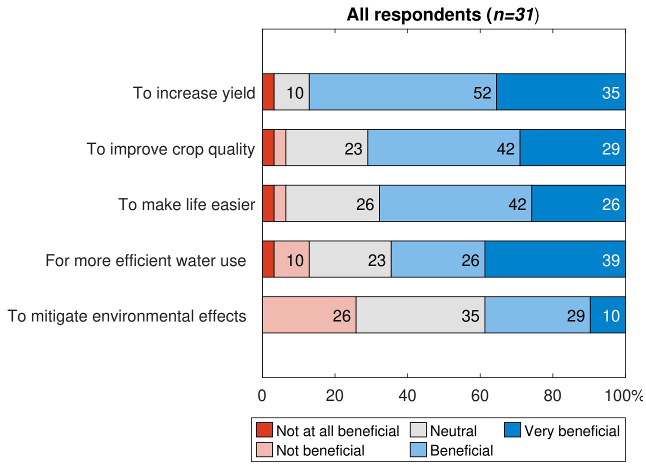

Fig. 3. Perceived benefits of automation in agricultural water management.

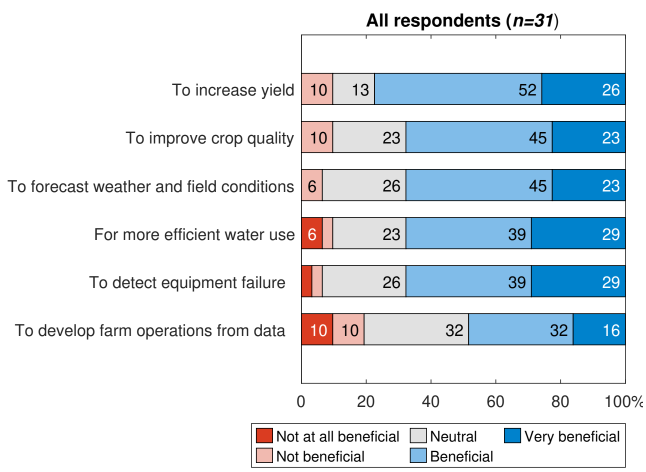

Fig. 4. Perceived benefits of monitoring in agricultural water management.

There was no specific question about forecasting in the survey, but some of its potential benefits emerged through the interviews. F1 reported that valve operations were often performed when the field was already wet or when the level in the control well was deemed too high or too low, meaning that the operation occurred late. This matches a comment from a farmer who said that they opened a valve because the field was wet. As drying processes are slow and the effect of opening wells can take time, predicting future conditions (groundwater level or soil moisture) could help farmers anticipate. Once the rain starts, they may only have a few hours to react (Lafond et al. (2021)).

4.3 Barriers to invest in water management technologies

Although farmers saw several benefits in automation and monitoring and were not against the use of automated systems for water management, only 1/3 of the respondents affirmed that they were willing to invest in technologies for water management. All of those who responded positively were farmers who have control wells and who were operating them more than twice a year.

The reasons given for the reluctance to invest in technologies for water management were the lack of interest in such a system, the low profitability of agriculture in Finland, or the fact that their current drainage system was sufficient for their needs. Besides, some farmers did not see the benefits of automation of the control wells when they had to go to the fields anyway and could operate the valves on site. F2 asserted that, in the end, the willingness to invest in a technology depends on the financial gain that the investment is predicted to bring.

Teaching and training farmers how to use the system properly is also paramount. Several farmers who have control wells commented that they did not receive enough clear guidance on how to use control wells. Others reported that the instructions they received did not apply to their fields.

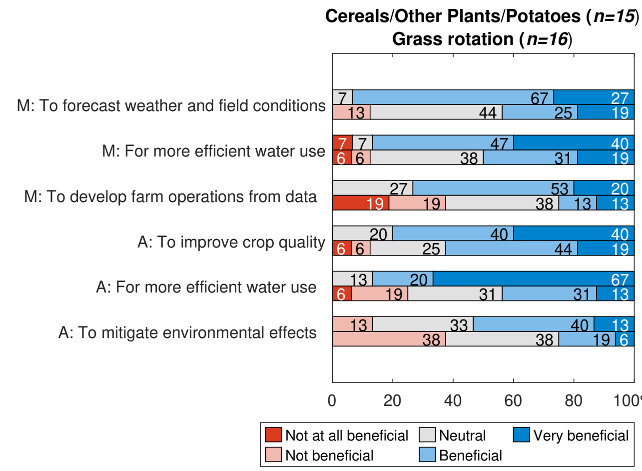

Fig. 5. Perceived benefits of automation (A) and monitoring (M) in agricultural water management. Upper bars are the responses from farmers cultivating cereals, potatoes or other plants as their main crop. Lower bars represent the responses from farmers doing grass rotation.

4.4 Factors influencing farmers' answers

Each farmer has their own priorities on their farm and devotes their energy and time to different subjects. Farmers in dairy production are likely to be less interested in investing in water management systems for the plants they cultivate (fodder) than farmers cultivating food for humans. Thus, potential factors that influence the evaluation of the benefits of monitoring and automation were analyzed.

The respondents were divided into groups according to the size of the farm, the main crops, the production sector, and whether they have control wells or not. For instance, farmers whose main crop was grass rotation (mainly grass and sometimes feed grains) were distinguished from the other farmers who cultivated cereals, potatoes, or other plants that have higher market values than grass. Farmers belonging to the first group generally assigned lower values to the benefits brought about by automation and monitoring than the others (Fig. 5). Concerning the benefits of automation, the clearest difference was regarding the opportunity to optimize water usage. For the advantages brought about by monitoring, the difference was most visible for the development of farm operations based on data.

Likewise, the frequency of control well valve operations was a key factor influencing the assessment of the benefits of monitoring and automation. These results confirmed the assumption that an automated water management system or monitoring would be primarily beneficial to farmers who cultivate high-value plants, such as potatoes (F4), or who regularly operate the valves. However, more responses are needed to confirm the influence of these factors.

5. CONCLUSIONS

An MPC controller for subsurface drainage was implemented and used during one summer in an experimental field. The experiment showed that MPC is the proper control design paradigm for the problem. The responses obtained from the survey and the interviews confirmed that farmers viewed an automated system of this kind as beneficial.

Based on the farmers' answers, the main lessons for the further development of automated controlled drainage systems are:

(1) Knowledge exchange and feedback activities with farmers are crucial: These activities require time and resources, but are mutually beneficial. The local expertise of farmers is essential to design an appropriate automated water management system.
(2) Model scope: Subsurface irrigation is already used by a proportion of farmers, so it is important to model irrigation in the groundwater prediction model. In addition, drought in the growing seasons will probably become more frequent, so irrigation could become more widespread (Ahopelto et al. (2023)). Some farmers were more interested in controlling soil moisture than groundwater height, and it seems relevant to include soil moisture modeling.
(3) Model structure and calibration: Each field has its own configuration (geometry, soil, crop, etc.), which evolves as e.g. works are done on the field or distinct types of plant are cultivated. Therefore, the prediction model must be generic enough to be easily calibrated and applicable to different fields.
(4) Prediction window: The drying of one field might take several months after opening the valve. Hence, it might be relevant to extend the MPC prediction window based on the field characteristic. However, the accuracy of the groundwater model is limited by the availability and reliability of weather forecasts.
(5) UI: As farmers use their smartphones when working on fields, the UI should be accessible from a Web browser and designed for both computers and smartphones. Relevant information that should be displayed on the UI is water level and soil moisture predictions, weather forecasts, and control suggestions.
(6) Farmers cultivating cash crops were generally more actively using control wells and more interested in automated water management systems than farmers in the animal production sector (milk, beef, or other animal production).

Ongoing work is dedicated to enhancing the groundwater model used by the MPC, taking into account the lessons learned from the discussions with farmers.

ACKNOWLEDGEMENTS

We thank the farmers for their answers and for their participation in the interviews. The answers were gathered as part of "Water management of cultivated peatlands based on catchment scale evaluation and groundwater level monitoring" project (TurPo, decision no. POPELY/3107/2022) which received funding from the North Ostrobothnia ELY Centre and the Ministry of the Environment. The MPC experiments were conducted in cooperation with the Kpedu, Kannus site. This research was a part of the Ministry of Education and Culture's Doctoral Education Pilot under Decision No. VN/3137/2024-OKM-6 (Digital Waters (DIWA) Doctoral Education Pilot related to the DIWA Flagship (decision no. 359228) funded by the Research Council of Finland's Flagship Programme).

REFERENCES

Ahopelto, L., Kallio, M., Veijalainen, N., Kouki, R., and Keskinen, M. (2023). Drought hazard and annual precipitation predicted to increase in the sirppujoki river basin, finland. *Climate Services*. doi: 10.1016/j.cliser.2023.100400.

Balaska, V., Adamidou, Z., Vryzas, Z., and Gasteratos, A. (2023). Sustainable crop protection via robotics and artificial intelligence solutions. *Machines*. doi: 10.3390/machines11080774.

Evans, C., Peacock, M., and Baird, A. (2021). Overriding water table control on managed peatland greenhouse gas emissions. *Nature*. doi:10.1038/s41586-021-03523-1.

Fyles, H. and Madramootoo, C. (2016). 6 - water management. In C. Madramootoo (ed.), *Emerging Technologies for Promoting Food Security*. Woodhead Publishing. doi:10.1016/B978-1-78242-335-5.00006-8.

Ikonen, E., Liedes, T., and Vasara, J. (2023). Model predictive controlled subsurface drainage and irrigation for peatland groundwater management. *IFAC-PapersOnLine*. doi:10.1016/j.ifacol.2023.10.667.

Lafond, J.A., Gumiere, S.J., Vanlandeghem, V., Gallichand, J., Rousseau, A.N., and Dutilleul, P. (2021). Temporal and local heterogeneities of water table depth under different agricultural water management conditions. *Water*. doi:10.3390/w13162148.

Lillestrøm, V., Haddara, M., and Langseth, M. (2024). Unlocking the potentials of iot adoption in agriculture: Insights from norwegian farmers. *Procedia Computer Science*. doi:10.1016/j.procs.2024.06.265.

Parra-López, C., Ben Abdallah, S., Garcia-Garcia, G., Hassoun, A., Trollman, H., Jagtap, S., Gupta, S., Aït-Kaddour, A., Makmuang, S., and Carmona-Torres, C. (2025). Digital technologies for water use and management in agriculture: Recent applications and future outlook. *Agricultural Water Management*. doi: 10.1016/j.agwat.2025.109347.

Salo, H., Salla, A., and Koivusalo, H. (2021). Seasonal effects of controlled drainage on field water balance and groundwater levels. *Hydrology Research*. doi: 10.2166/nh.2021.056.

van de Craats, D., van der Zee, S.E.A.T.M., and Leijnse, A. (2021). Anticipatory drainage base management for groundwater level optimization. *Water Resources Research*. doi:10.1029/2021WR029623.