Smart drainage management to limit summer drought damage in Nordic agriculture under the circular economy concept

Syed Md Touhidul Mustafa[1], Kedar Ghag[1], Anandharuban Panchanathan[1], Bishal Dahal[1], Amirhossein Ahrari[1], Toni Liedes[1], Hannu Marttila[1], Tamara Avellán[1], Mourad Oussalah[1], Bjorn Klove[1], and Ali Torabi Haghighi[1]

[1]Oulun yliopisto

March 16, 2022

Smart drainage management to limit summer drought damage in Nordic agriculture under the circular economy concept

Syed Md Touhidul Mustafa [1, *], Kedar Ghag[1], Anandharuban Panchanathan[2], Bishal Dahal [1], Amirhossein Ahrari[1], Toni Liedes [3], Hannu Marttila[1], Tamara Avellán[1], Mourad Oussalah[2], Björn Klöve [1], & Ali Torabi Haghighi[1]

[1]Water, Energy and Environmental Engineering Research Unit, University of Oulu, P.O. Box 4300, FIN90014, Oulu, Finland

[2]Center for Machine Vision and Signal Analysis, University of Oulu, Finland

[3]Intelligent Machines and Systems, University of Oulu, PO Box 4200, 90014 Oulu, Finland

1. Introduction

Water excess and shortage (drought) are becoming more frequent phenomena that challenge the development of agriculture and crop production in Nordic countries. Indeed, water excess has been traditionally the main cause for crop failure in Nordic agriculture, and waterlogging causes substantial yield losses in this region (Bertholdsson, 2013; Wiréhn, 2018; Sundgren et al., 2018). In addition, drought in early summer, related to low snow conditions and early summer heatwaves occurring at crop water-sensitive stages, is a recurring phenomenon in the Nordic region. Lack of water causes substantial (10 - 20 %) irreversible yield losses of crops (Peltonen-Sainio et al., 2021), which undermine food production. For example, the 2018 summer drought in the Nordic region has reduced cereal yield by 40 - 50 % (Bakke et al., 2020; Beillouin et al., 2020; Statistiska-Meddelanden, 2018). These challenges are amplified by the uncertainty and the expected long-term effect caused by climate change's impact on hydrological variables like precipitation, temperature, and soil moisture (Vautard et al., 2013; Putnam and Broecker, 2017; Ruosteenoja et al., 2017) as well as seasonal changes. The projected increase in precipitation in Northern Europe is mainly concentrated in winter and autumn, while precipitation is predicted to decrease in spring and summer (Chan et al., 2020; Rummukainen et al., 2004). Furthermore, global climate model projections show that the long-term mean soil moisture will decline in spring in northern Europe (Ruosteenoja et al., 2017), which can negatively affect agricultural crop production here.

To tackle the water excess and summer drought challenges, drainage, irrigation and crop choices are often promoted as ideal solutions. Nevertheless, the effective implementation of such solutions is open to debate both from technical and regulatory perspectives. To handle wet periods, drainage is required in most agricultural fields in the Nordic region to handle waterlogging (Jacks, 2019; Järvenpää and Savolainen, 2015). Additionally, supplemental irrigation is often required during drought conditions, but the existing field setting is yet not well equipped for irrigation. Nevertheless, implementing a supplemental irrigation strategy is quite challenging if the field is far from natural lakes or streams, which is often the case in lowland regions. Groundwater has also been suggested as a potential solution to provide irrigation potential. However, long-term dependence on groundwater for irrigation may have considerable adverse effects on environmental conditions, which need special consideration. This calls for further research on the issue. Controlled drainage, whereby drainage water release or retention from the field is regulated, can be used as a potential solution to limit summer drought damage and reduce nutrient loading to surface water.

In Europe, diffuse nutrient pollution (e.g., around 90 % of phosphorous and about 70 % of nitrogen) from agriculture, mainly due to poorly managed subsurface drainage systems, is a primary concern for the ecological health of European river basins (Grizzetti et al., 2021). At the same time, fertilizer use is expensive but considered necessary to achieve good crop yields. Taking advantage of nutrients available in drainage waters may provide an avenue to the reduction of fertilizer use on the fields and, at the same time, reduce the nutrient pollution of surface, sub-surface and coastal waters.

Circular Economy (CE) is a mindset that intends to move away from the end-of-pipe systems and linear approaches towards restorative and regenerative business models by intention and design (MacArthur, 2013). In the European Union (EU), the Nordic region is no exception to this trend where political actions have received much attention in the past years to accelerate the transition towards a circular economy (Rodríguez-Antón et al., 2021, Hosseinian et al., 2021). The Finnish Roadmap to circular economy from 2016, for instance, highlights sustainable food systems as one of the four focus areas and stresses the need for utilizing recycled fertilizers (Hosseinian et al., 2021). Changing the management of drainage waters from linear to circular systems and thus taking advantage of the embedded fertilizers in the drainage water for fertigation purposes (fertilizing with irrigation water) may promote technological loops that reduce waste, enhance reuse and result in stable crop yields in light of climate change.

The reuse and improved use of drainage water for fertigation through improved drainage control could be an essential strategy to reduce yield losses during summer drought and nutrient loading to surface water. We present a simple, flexible, and eco-friendly approach to reusing drainage water for fertigation through improved drainage control and promoting a circular economy in challenging Nordic conditions. This also joins the European Union (EU)'s effort to accelerate the transition towards the circular economy to achieve the Sustainable Development Goals (SDGs).

2. Multi-module smart drainage management approach

Our proposed simple smart drainage management approach to reuse drainage water for fertigation through improved drainage control for overcoming summer drought consists of three modules (Figure 1): (i) meteorological forecasting, (ii) hydrological simulation, and (iii) the practical implementation of irrigation and drainage control using novel ICT-based sensor network solutions. The implementation module has two parts: an automatic drainage control regulating the amount of agricultural field water and the reuse of drainage water for fertigation feeding back in an automatically controlled manner into the drainage system.

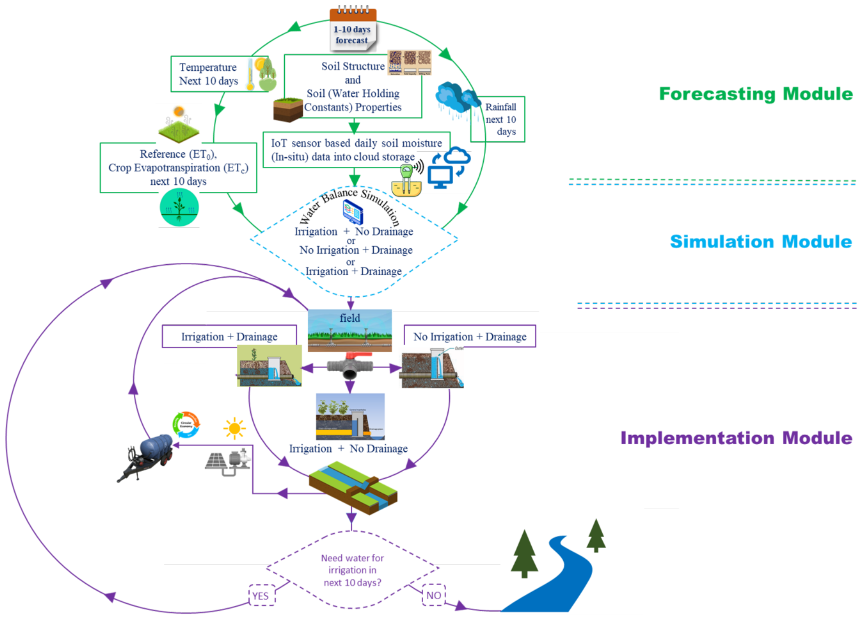

Figure 1: The proposed multi-module smart drainage management approach.

2.1 Meteorological Forecasting Module

In the first module, the forecasted hydro-climatological data of the study area are collected and characterized in detail. The 1-10 day forecasted rainfall and temperature data, provided by regional authorities and meteorological institutes, are used as initial input. The forecasted temperature is applied to estimate the daily reference evapotranspiration (ET_0). The crop evapotranspiration (ETc) will be calculated based on the ET_0 and crop coefficient (Kc) in the different growth stages.

2.2 Hydrological Simulation Module

Using ETc, current soil water holding, and forecasted rainfall, the daily soil moisture will be estimated for the next 10 days using the Water Balance Simulation (WBS) in the hydrological simulation module. The results of the WBS will propose tentative irrigation or drainage demand values to farmers (or system operators). This provides the basis to implement optimal irrigation or drainage management.

In the first step of the implementation module, the water level in the crop field will be optimized by using the automatic drainage control system. For instance, if currently (e.g., today) the field has enough water, but no (or deficit) rainfall is forecasted within the next 10 days, the drainage valve will automatically be closed (or partially closed) to keep soil moisture near the root zone. Conversely, if an extreme rainfall event is forecasted, a drainage valve will automatically be fully opened to facilitate drainage and avoid waterlogging. WBS simulation takes advantage of the ICT sensors by considering soil hydraulic properties (e.g. soil water retention curve) to regulate the drainage outflow.

2.3 Implementation Module using novel ICT based sensor network

In the final part of the implementation module, the excess drained water from heavy rainfall events can be stored in a buffer pond or portable storage tank (Fig. 1). Some parts of the drainage ditch, beside the field, can be used as a buffer pond by applying a water level controller. During a summer drought, the stored water can be used for fertigation. Care needs to be taken in assessing the water quality of the stored water, thus avoiding excess fertilization and degradation of soils (i.e. through heavy metals, salinization, etc.). The assessed irrigation water can be fed back through the existing drainage system using these as underground irrigation pipes, thus avoiding additional irrigation infrastructure and using emission-free systems (e.g. solar pumps). An elevated storage tank can also help overcome the possible uncertainty in the weather predictions. A solar pump will be applied to store drained water into a portable storage tankwhich can then be used for fertigation by gravity flow. Given the climatic conditions of the Nordic region, the tank can be filled with melted water from snow before the cropping season. Additionally, the drainage water recycling reduces nutrient loading to surface water from agriculture.

3. Conclusions

The proposed smart drainage management approach will reduce yield losses during summer drought and also reduce nutrient loading to surface water from the agricultural field. Application of solar panels, reusing drainage water and reducing the nutrient loads are supportive of the concept of circular economy and sustainable resources management. The presented approach can lead to optimizing resources in the Water-Energy-Food Nexus of Nordic agriculture. The key advantages of the proposed approach are: (i) It is simple, flexible, and eco-friendly; (ii) It can support sustainable crop production in the Nordic region by reducing yield losses during summer drought; (iii) It contributes to the European Union Water Framework Directive's (WFD) by potentially reducing nutrient loading from agricultural fields to surface and sub-surface waters; (iv) It supports the use of renewable energy sources in line with the EU Green Deal and COP26 objectives, and; (v) It supports UN SDGs (SDG goal 6, targets 6.3 and 6.4) as it promotes the safe reuse of agricultural drainage water for irrigation and provides opportunities to increase water use efficiency.

References

Bakke, S. J., Ionita, M., & Tallaksen, L. M. (2020). The 2018 northern European hydrological drought and its drivers in a historical perspective. Hydrology and Earth System Sciences, 24(11), 5621-5653.

Beillouin, D., Schauberger, B., Bastos, A., Ciais, P., & Makowski, D. (2020). Impact of extreme weather conditions on European crop production in 2018. Philosophical Transactions of the Royal Society B, 375(1810), 20190510.

Bertholdsson, N. O. (2013). Screening for barley waterlogging tolerance in nordic barley cultivars (Hordeum vulgare L.) using chlorophyll fluorescence on hydroponically-grown plants. Agronomy, 3(2), 376-390.

Chan, S. C., Kendon, E. J., Berthou, S., Fosser, G., Lewis, E., & Fowler, H. J. (2020). Europe-wide precipitation projections at convection permitting scale with the Unified Model. Climate Dynamics, 55(3), 409-428.

Grizzetti, B., Vigiak, O., Udias, A., Aloe, A., Zanni, M., Bouraoui, F., . . . & Bielza, M. (2021). How EU policies could reduce nutrient pollution in European inland and coastal waters. Global Environmental Change, 69, 102281.

Grusson, Y., Wesström, I., & Joel, A. (2021). Impact of climate change on Swedish agriculture: Growing season rain deficit and irrigation need. Agricultural Water Management, 251, 106858.

Hosseinian, A., Ylä-Mella, J., & Pongrácz, E. (2021). Current Status of Circular Economy Research in Finland. Resources, 10(5), 40.

Jacks, G. (2019). Drainage in Sweden-the past and new developments. Acta Agriculturae Scandinavica, Section B—Soil & Plant Science, 69(5), 405-410.

Järvenpää, L., & Savolainen, M. (2015). Maankuivatuksen ja Kastelun Suunnittelu (Making Plans for Agricultural Drainage and Irrigation). 2nd ed., Environmental Administration Guidelines 4/2015, Juvenes Print: Tampere, Finland, ISBN 978-952-11-4517-9.

MacArthur, E. (2013). Towards the circular economy. Journal of Industrial Ecology, 2, 23-44.

Peltonen-Sainio, P., Juvonen, J., Korhonen, N., Parkkila, P., Sorvali, J., & Gregow, H. (2021). Climate change, precipitation shifts and early summer drought: An irrigation tipping point for Finnish farmers?. Climate Risk Management, 33, 100334.

Putnam, A. E., & Broecker, W. S. (2017). Human-induced changes in the distribution of rainfall. Science Advances, 3(5), e1600871.

Rodríguez-Antón, J. M., Rubio-Andrada, L., Celemín-Pedroche, M. S., & Ruíz-Peñalver, S. M. (2021). From the circular economy to the sustainable development goals in the European Union: An empirical comparison. International Environmental Agreements: Politics, Law and Economics, 1–29.

Rummukainen, M., Bergström, S., Persson, G., Rodhe, J., & Tjernström, M. (2004). The Swedish regional climate modelling programme, SWECLIM: a review. AMBIO: A Journal of the Human Environment, 33(4), 176-182.

Ruosteenoja, K., Markkanen, T., Venäläinen, A., Räisänen, P., & Peltola, H. (2018). Seasonal soil moisture and drought occurrence in Europe in CMIP5 projections for the 21st century. Climate Dynamics, 50(3), 1177-1192.

Statistiska-Meddelanden (2018). Skörd av spannmål, trindsäd, oljeväxter och slåttervall 2018. Sveriges officiella statistik JO 19 SM 1802.

Sundgren, T. K., Uhlen, A. K., Waalen, W., & Lillemo, M. (2018). Field screening of waterlogging tolerance in spring wheat and spring barley. Agronomy, 8(4), 38.

Szejba, D. (2020). Importance of the Influence of Drained Clay Soil Retention Properties on Flood Risk Reduction. Water (Switzerland) 12 (5).*https://doi.org/10.3390/W12051315*.

Vautard, R., Gobiet, A., Jacob, D., Belda, M., Colette, A., Déqué, M., . . . & Yiou, P. (2013). The simulation of European heat waves from an ensemble of regional climate models within the EURO-CORDEX project. Climate Dynamics, 41(9-10), 2555-2575.

Wiréhn, L. (2018). Nordic agriculture under climate change: A systematic review of challenges, opportunities and adaptation strategies for crop production. Land use policy, 77, 63-74.