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Keywords: water reuse, irrigation, optimal control

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1 Background

Irrigation with treated wastewater, also known as water reuse, is currently considered as a solution to provide water to crops and is used in arid regions where water scarcity is an important challenge, limiting the development of agriculture. However, wastewater contains nutrients that are essential to crops and therefore provides the opportunity to fertilize crops from a renewable source. Managing water treatment processes to avoid degrading nutrients whilst removing pathogens and micro-pollutants remains a challenge but is an active research area. There are also dangers associated with over-fertilization as it can lead, for example, to nitrate leaching. Recent studies have shown that it is possible, in a treatment process, to dynamically control the quality and quantity of nutrients, opening up the possibility of adapting wastewater treatment to the changing needs of crops through a growth cycle. There is thus a need to determine the optimal requirements of crops whilst considering the environmental impacts of reuse irrigation.

2 Aims

Models are valuable tools for the estimation of yield, crop and soil quality as a function of farming practices and can therefore play an important role in designing and operating a reuse system. Indeed, a crop model can be used to determine irrigation and nutrient requirements for optimal crop growth, in order to obtain setpoints for water quality to be passed on to a treatment facility. In this context, we study here an optimal control problem focusing on a field irrigated with reuse water, and consider nitrogen (N) to represent the plant nutrients. We take into account the different objectives of maximizing crop biomass and minimizing irrigation and environmental costs. The controls are the irrigation volume and nitrogen concentration of the irrigation water.

3 Materials and methods

Although there are a variety of well validated crop models, most cannot be used for standard control techniques because their mathematical structure is unclear and they are essentially simulation models (Cobbenhagen 2021). Instead we propose a double modeling method, in which a dynamic systems model - the 'control model' - is used in parallel with a detailed simulation model. The control model is designed to capture the essential dynamics relating to the controlled inputs whilst being adapted to the resolution and understanding of the problem and we use here the model from (Pelak 2017). The simulation model (Brisson 2003) is considered for its detailed representation of the cropping system and is used to guarantee the validity of the results.

In practice, for a given scenario (i.e. a fixed set of parameters of the simulation model) and an initial guess of the inputs, the control model parameters are calibrated to get a good agreement between outputs of both models. Then, the problem for the control model can be solved and we use a dynamic programming technique (Bonnans 2017). To deal with the multiple objectives, we recast the problem as a constrained optimal control problem by considering an optimization criterion only on the final crop biomass and setting the other objectives as constraints. These are irrigation costs and the environmental impact of nitrate leaching and we thus impose an upper bound on the total amount of nitrogen added through irrigation. Then by solving the problem for different values of the constraint, we get a range of optimal controls and an associated Pareto front, from which we can analyze the trade-offs between the different objectives. Finally, the results can be further evaluated with the simulation model. This also allows to assess the quality of the control model by comparing it with the simulation model over the range of computed controls.

4 Results

We illustrate our method with a case study, which represents a modern corn cultivar grown on a loam type soil with weather data from 2013. We have found that, with a single set of parameters calibrated initially from a simulation with reference controls, it is possible to reproduce the outputs of the simulation model for a range of controls, as Figures 1 and 2 show. Furthermore, with this approach we can understand the relation between the different objectives and, for example, with the control model we find the same values as the simulation model for which no extra more fertilization or irrigation does not produce more crop biomass. This demonstrates the quality of the double modelling method and of the control model, which can therefore serve as part of a future decision making tool.

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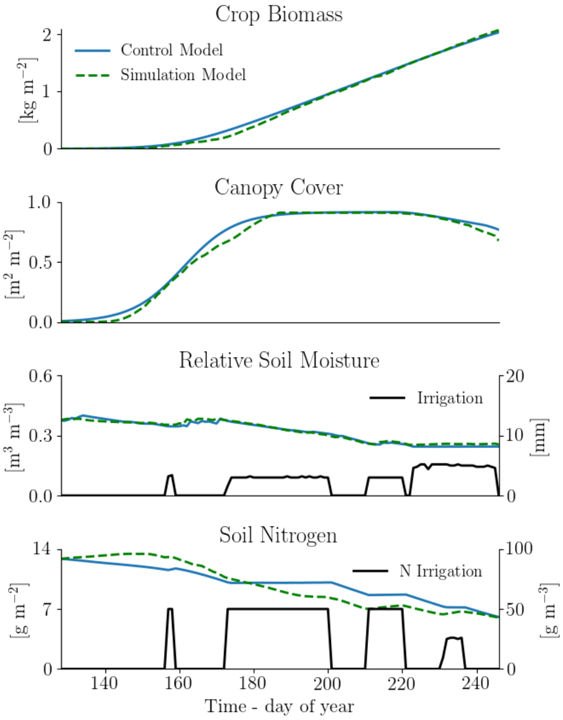

Figure 1. Controls and variables of control and simulation model for 70 kg/ha total N irrigation.

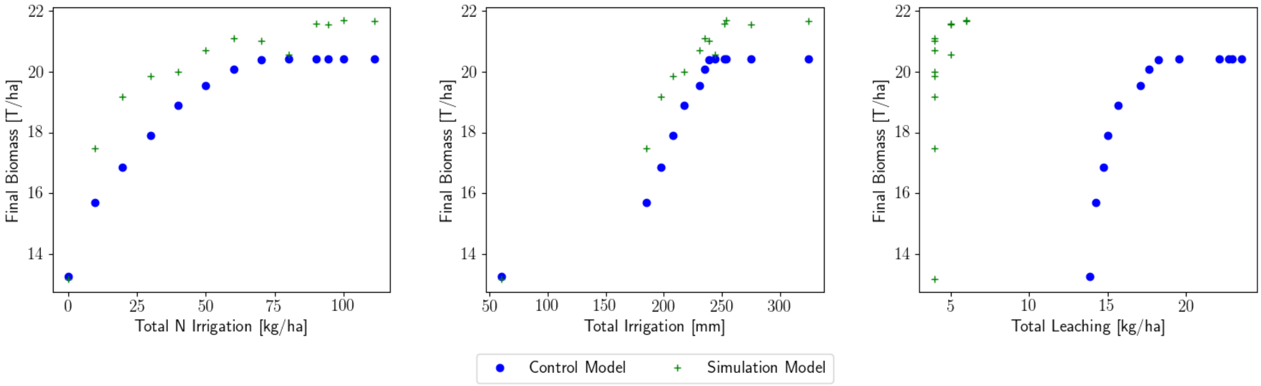

Figure 2. Final biomass for computed controls as a function of the constraint of total N irrigation (left) and the other objectives: total irrigation (center) and total N leached (right), values from control model and simulation model.