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Management model for decision support when applying low quality water in irrigation

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ABSTRACT

Use of low quality water for irrigation of food crops is an important option to secure crop productivity in dry regions, alleviate water scarcity and recycle nutrients, but it requires assessment of adverse effects on health and environment. In the EU-project "SAFIR[1]" a model system was developed that combines irrigation management with risk evaluation, building on research findings from the different research groups in the SAFIR project. The system applies to field scale irrigation management and aims at assisting users in identifying safe modes of irrigation when applying low quality water. The cornerstone in the model system is the deterministic "Plant–Soil–Atmosphere" model DAISY, which simulates crop growth, water and nitrogen dynamics and if required heavy metals and pathogen fate in the soil. The irrigation and fertigation module calculates irrigation and fertigation requirements based on DAISY's water and nitrogen demands. A Water Source Administration module keeps track of water sources available and their water quality, as well as water treatments, storage, and criteria for selection between different sources. At harvest, the soil concentrations of heavy metals and pathogens are evaluated and the risk to consumers and farmers assessed. Crop profits are calculated, considering fixed and variable costs of input and output. The user can run multiple "*what-if*" scenarios that include access to different water sources (including wastewater), water treatments, irrigation methods and irrigation and fertilization strategies and evaluate model results in terms of crop yield, water use, fertilizer use, heavy metal accumulation, pathogen exposure and expected profit. The management model system can be used for analysis prior to investments or when preparing a strategy for the season.

1. Introduction

In many places around the world, fresh water is a scarce resource. Re-use of wastewater in irrigation is one option to alleviate the scarcity and improve nutrient recycling. However, use of low quality water for irrigation of food crops immediately raises concerns in consumers and authorities administering food quality and health. As a result, the water quality legislation controlling the use of reclaimed water for irrigation is quite strict in some countries. For example, the Italian law 152/06 admits a maximum of 0.1 cfu (colony forming unit) ml^{-1} *Escherichia coli* for direct wastewater use. This is considerably stricter than the WHO (2006)-recommendations of 6–7 log unit reductions of the *E. coli* content in raw wastewater (10^8 to 10^{10} cfu L^{-1}), where part of the reduction may take place after application. To obtain such low *E. coli*-content, extensive and expensive pre-treatment of water is required. On the other hand, wastewater is used for irrigation in countries such as Pakistan (Ensink et al., 2004) and Mexico (Scott et al., 2000) and the resulting produce is important for local food security and as a source of income.

Several models exist that calculate irrigation water requirement, from a number of simple water balance models represented by e.g. CROPWAT (Smith, 1992), over single-field models such as DAISY (Abrahamsen and Hansen, 2000) or SALTMED (Ragab, 2002) to decision support systems, which again range from simple balance models such as Pl@nteInfo® (Jensen et al., 2000), SIMIS (Mateos et al., 2002) or IRRINET (CER, 2009, http://irrigation.altavia.eu/logincer.aspx) to systems that integrate remotely sensed data for precision farming (Pinter et al., 2003). Fewer systems include nutrients and fertigation, e.g. Anastasiou et al. (2009) or Heiswolf et al. (2010). No models for calculation of crop water requirement were found that aim at incorporating hazards related to the use of wastewater, although SALTMED describes effects of salt on crop growth.

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The hazards associated with wastewater mainly relate to pathogens, heavy metals and organic contaminants. These contaminants may be hazardous to the farmers working with the water and the consumers exposed to the produce. Particularly for heavy metals, accumulation may take place in the soil over time, thus increasing the risk of significant plant uptake (Chang et al., 1995). WHO (2006) provides general guidelines of how to assess such risks. Furthermore, leaching of contaminants (McBride, 1997) as well as the nutrients added with wastewater is an environmental concern to consider.

In the EU-project "SAFIR" (www.safir4eu.org), summarized by Plauborg et al. (2010a), it was attempted to combine research findings from the different research groups in an irrigation management model that could aid decision making regarding use of wastewater. The project concerned itself with irrigated tomatoes and potatoes, primary and secondary wastewater (and tap water), pathogens and heavy metals and four different water treatment methods at six field sites. Full irrigation, regulated deficit irrigation and the irrigation method "partial root drying" were investigated. The work with the management model for irrigation with wastewater aimed at covering the combinations investigated in the field. The model system integrates analysis of when to irrigate and fertigate, based on soil water content criteria and assessment of crop nitrogen requirements, and analyses of health and environmental aspects of the applied water. The effect of different treatments of low quality water is simulated. Furthermore, profit calculations of the different tested scenarios are carried out. Thus, it is possible to evaluate combinations of water sources, water treatment methods, irrigation methods and strategies with respect to water use, hazards and costs. The model system may be used for pre-investment analysis or to evaluate a growing strategy for the next season. An earlier version of the model concept is described in Refsgaard and Styczen (2006).

This article describes the model system that was assembled. Data obtained in the project has been used to derive the relationships and to calibrate sub-models; as yet the model system has not been validated on sites with independent data.

2. Theory and model description

The model system, which is described in detail in Styczen et al. (2009) consists of (Fig. 1):

(1) The Plant–Soil–Atmosphere model (PSA-model), DAISY (Abrahamsen and Hansen, 2000; Hansen et al., 1990). This model was further developed under the SAFIR-project, as described in Plauborg et al. (2010b),
(2) an Irrigation and Fertigation Strategy module (IF-module),
(3) a Water Source Administration module (WSA-module),
(4) a Risk Assessment module (RA-module) and
(5) an Economy module.

The PSA-model is linked to the IF-module and to the WSA-module via an OpenMI-interface (Gijsbers, 2004), which is a standardized framework for linking environment-related models. OpenMI allows the user to let the prediction of one model depend on the state predicted by another model. An overview of the model system is given in Fig. 1.

The cornerstone in the model system is the "Plant–Soil–Atmosphere" (PSA)-model. It simulates water, carbon and nitrogen dynamics (including crop growth) and if required, heavy metals and pathogen fate in the soil. The IF-module repeatedly questions the PSA model for its water and nitrogen demands. In turn the IF-module requests water from the WSA-module, which keeps track of available water sources and their water quality, water treatments, storage, and criteria for selection between different sources. After receiving water of a certain quality from the WSA-module, the IF-module supplies water and nitrogen back to the PSA, according to a defined irrigation strategy. At harvest, the soil concentrations of heavy metals and pathogens are calculated and the risk to consumers and farmers assessed. Crop profits are assessed, considering fixed and variable costs of input and output.

Using a Microsoft Excel result presentation, users get access to key performance figures from the model simulation, including crop

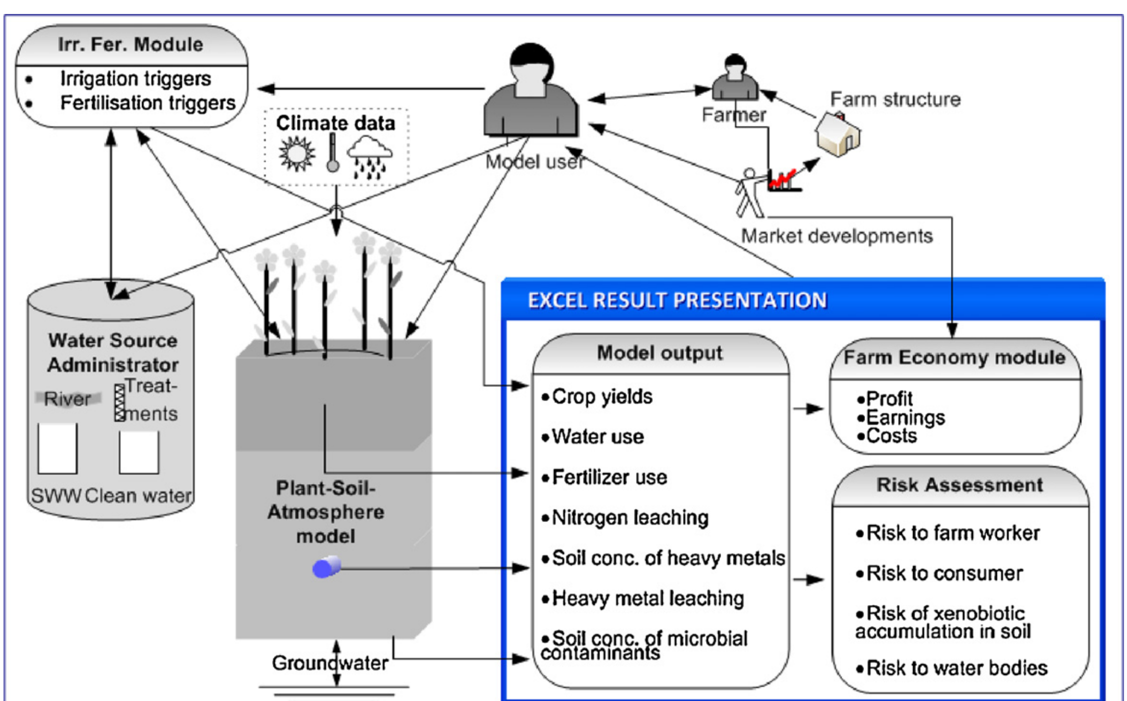

Fig. 1. Overview of the management model system made within the SAFIR project. The Plant–Soil–Atmosphere model used in the project is DAISY (Abrahamsen and Hansen, 2000).