Matching agricultural freshwater supply and demand: using recycled water for subirrigation purposes

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Abstract:

We are increasingly confronted with drought damage in agriculture and nature, as well as an increasing pressure on the availability of water for high-grade applications, such as the production of drinking water. Strategies are being developed to control these risks and to secure long-term supplies of freshwater. These include increasing regional self-sufficiency to meet the demand for freshwater and improving the utilization of available water sources. We provide results of a pilot study in which industrial treated wastewater (TWW) is used for subirrigation in an agricultural field. Results show that the water availability for crops can be optimized by subirrigation with TWW as water source, and the need for groundwater or surface water extraction decreases.

Keywords: Drought; Industry; Subirrigation; Treated waste water; Water reuse

Introduction

Agricultural crop yields depend largely on soil moisture conditions in the root zone. Climate change leads to more prolonged drought periods that alternate with more intensive rainfall events. With unaltered water management practices, reduction in crop yield due to drought stress will increase. Therefore, both farmers and water management authorities search for opportunities to manage risks of decreasing crop yields. Available groundwater sources for irrigation purposes are increasingly under pressure due to regional coexistence of land use functions that depend on groundwater levels or compete for available water. At the same time, treated wastewater from industries and domestic wastewater treatment plants is quickly discharged via surface water towards sea. Exploitation of these freshwater sources may be an effective strategy to balance regional water supply and agricultural water demand.

In order to reduce the risk of waterlogging, farmers have drained their land to get rid of excessive soil moisture quickly. In order to limit excessive drainage, controlled drainage systems have been developed, which allow to retain groundwater within agricultural parcels. Such controlled drainage allows to actively control groundwater levels and soil moisture conditions at an agricultural field (Ayars et al. 2006). Moreover, water can be actively added to the system, which turns a controlled drainage system into an infiltration system, which is called subirrigation. The goal of subirrigation is to raise the groundwater level and improve the soil moisture conditions for plant growth through capillary rise. Subirrigation is a subsurface irrigation method that can be more efficient than classical, aboveground irrigation methods using sprinkler installations, as only water that is used for plant transpiration leaves the groundwater system. Unused water is kept within the groundwater system. Subirrigation is very much valued in growing crops as direct evaporation loss is reduced and the energy consumption is low (Bigah et al. 2019).

In this study, we use TWW as external freshwater source for subirrigation purposes. Such direct use of TWW for irrigation provides better control over soil moisture, hence better growing conditions for crops, and a reduced need for groundwater or surface water extraction. Additionally, subsurface irrigation has the advantage over surface irrigation that direct contact of the TWW with the plant is minimized.

A pilot study to examine the effects of the use of TWW in a subirrigation system has taken place at the Bavaria Beer Brewery in the south of the Netherlands (Figure 1, Bartholomeus et al. (2018)). The Bavaria Beer Brewery extracts a large amount of groundwater and discharges TWW to the surface water. At the same time, neighbouring farmers invest in sprinkler irrigation using groundwater to maintain their crop production during drought periods. This leads to increasing pressure on the regional groundwater availability. To reduce the water footprint of the brewery and the abstractions of farmers, excess TWW is delivered to a nearby field by subirrigation.

Within the pilot study, a subirrigation system has been installed and tested. We combine both process-based modeling of the soil-plant-atmosphere system and field experiments to i) investigate the amount of water that needs to be and that can be subirrigated, and ii) quantify the effect on soil moisture availability and herewith reduced needs for aboveground irrigation.

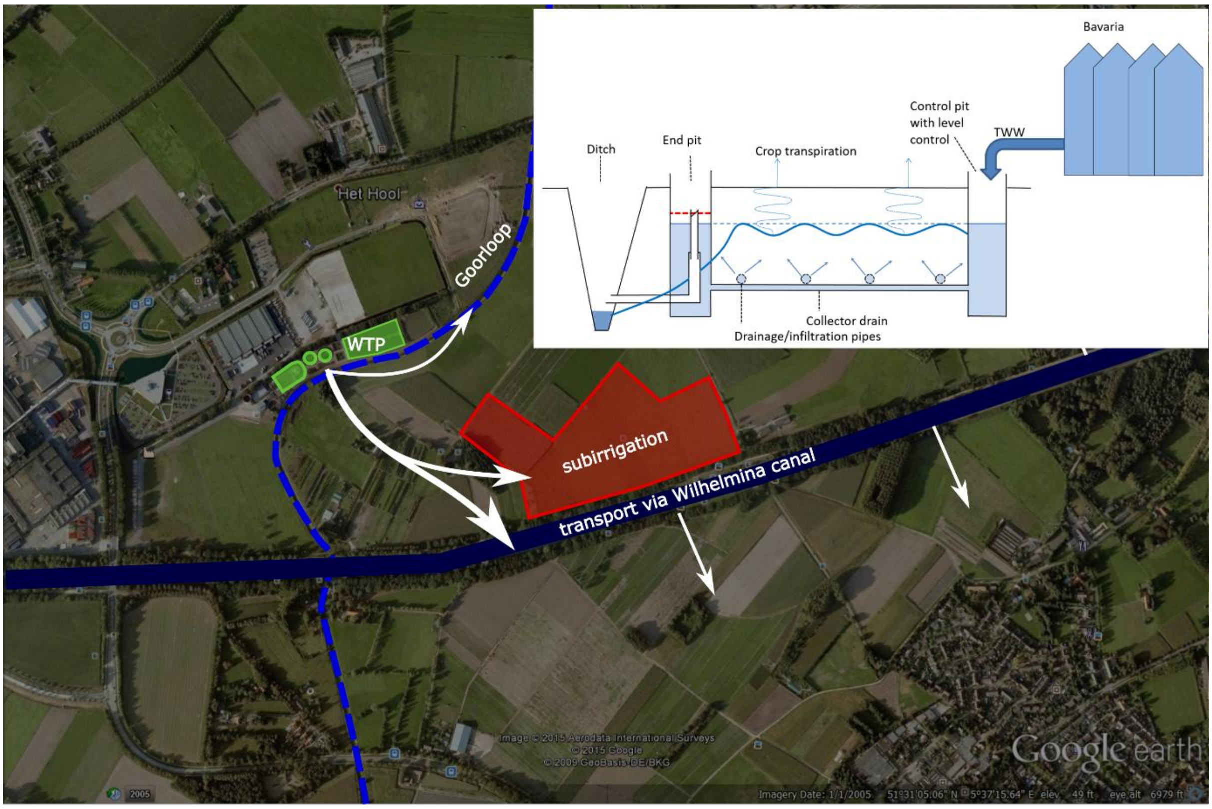

Figure 1 TWW from the Bavaria wastewater treatment plant (‘WTP’, green) is discharged via three routes: directly to the plot of agricultural land (‘subirrigation’, red) and to the Wilhelmina canal (dark blue). The canal transports TWW to fields at a greater distance from the WTP. The (conventional) discharge to the Goorloop (light blue) is minimized. Inset: schematic view of the subirrigation-system with TWW as water source for the Bavaria-case.

Material and Methods

A subirrigation system has been installed by using subsurface drains, which are interconnected through a collector drain, and connected to an inlet control pit for the TWW to enter the subirrigation system (Figure 1). A network of sensors has been installed to measure both the effect of subirrigation on i) groundwater levels and soil moisture contents in the root zone within the field ii) hydraulic heads in deeper aquifers and iii) groundwater levels in neighbouring fields. The water supply to the field is measured continuously at the wastewater treatment plant.

We used the Soil Water Atmosphere Plant model (SWAP; Kroes et al. (2009)) to describe the interacting processes in the soil-water-plant-atmosphere system. SWAP uses as input meteorological conditions, soil physical parameters, hydraulic head and a resistance to describe seepage/infiltration, a schematization of the drainage to local surface water and crop characteristics. Relevant output is groundwater level, soil moisture conditions in the root zone, soil temperature and reduction of the potential transpiration to the actual transpiration due to either too dry or too wet conditions in the root zone.

SWAP is combined with PEST (Doherty 2010) to calibrate the SWAP model against measured groundwater levels and soil moisture conditions at 40 and 60 cm-s.s. for the years 2015-2017. Soil physical parameters, vertical resistance of the aquitard, drainage resistances to the surface waters and drainage and infiltration resistance of the drainage/subirrigation system were fitted.

Results and Discussion

In 2015, the year without subirrigation, groundwater levels in summer dropped to about 250 cm-s.s. 2016 was not representative for a drought study, due to excessive rainfall in June/July. In 2017, a total of 430 mm of excess TWW was delivered to the field and groundwater levels raised to 50-100cm-s.s. Time series of groundwater levels indicate that the effect of subirrigation was limited to the target field; groundwater levels in neighbouring fields were not affected.

Subirrigation raised the groundwater level by 100–150 cm compared with the reference without subirrigation (Figure 2). According to the SWAP simulations, this shallow groundwater level optimized the soil moisture conditions for crop growth, i.e. transpiration reduction due to drought equaled zero for the situation with subirrigation and thus no drought stress occurred.

From the first calibration step, using SWAP-PEST, followed that the model performs well on average, but that simulated groundwater levels were too deep during subirrigation in 2016 and too shallow for 2017. The measurements indicate that the infiltration resistance is not a constant, but increases in time, because an increasing water level is needed in the control pit (Figure 1) and infiltration rates decrease over time. Therefore, in a second calibration step, we fitted the infiltration resistance for each month, while keeping the other fitted parameters to their values of the first calibration step. This gives a good agreement between the modeling results and the measurements (Figure 2). The gradual increase of the infiltration resistance is caused by clogging, and hampers optimal management of the groundwater level and herewith soil moisture conditions in the field. Nevertheless, alternating drainage and infiltration regimes will likely prevent clogging.

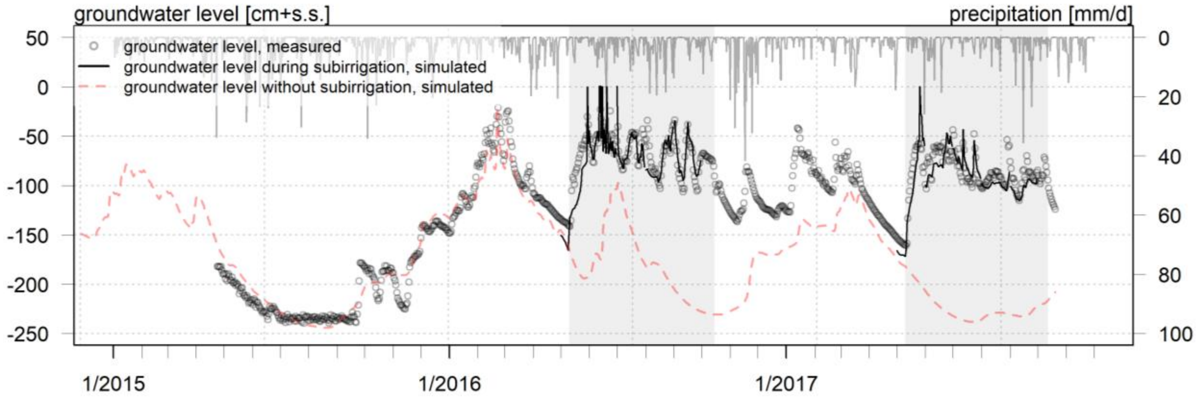

Figure 2 Precipitation and measured and simulated groundwater levels. The grey areas indicate the subirrigation periods.

Besides industrial wastewater treatment plants, domestic wastewater treatment plants across the Netherlands produce annually 40-50 mm freshwater which is discharged on surface water. Unlike most industrial effluent, domestic wastewater contains a variety of micro pollutants. Additionally, direct reuse of domestic TWW for agriculture is part of the EU regulation on water reuse (Dingemans et al. 2018). A similar pilot project as for Bavaria has been setup in the eastern part of the Netherlands, in which domestic TWW is applied to a corn field by subirrigation during the growing season from 2015 onwards, using a climate adaptive drainage system (Bartholomeus et al. 2017). Focus of this pilot study is on i) quantifying potential contamination of both the root zone and the deeper groundwater with emerging contaminants like pharmaceutical residues and ii) analyzing the effect of soil passage on surface water quality.

Conclusions

In this paper we focus on the water quantity effects of reusing treated wastewater for subirrigation purposes. The Bavaria-case indicates that subirrigation with TWW may be an effective method to i) increase groundwater levels, even at sites with normally relatively deep groundwater levels ii) optimize soil moisture conditions for crop growth and prevent drought stress. It should be noted, however, that the local soil conditions are important to prevent quick losses due to deep percolation and that clogging may be a serious risk. Utilizing available alternative water flows for agricultural water supply can reduce the demand for groundwater for sprinkling purposes, which spares the groundwater for more high-grade applications.

References

Ayars, J. E., E. W. Christen and J. W. Hornbuckle (2006). Controlled drainage for improved water management in arid regions irrigated agriculture. Agricultural Water Management **86**(1–2): 128-139.

Bartholomeus, R. P., S. F. Stofberg, G. A. P. H. Van den Eertwegh and D. G. Cirkel (2017). Hergebruik restwater voor zoetwatervoorziening in het landelijk gebied: Monitoring sub-irrigatie met RWZI-effluent Haaksbergen - 2016. Nieuwegein, KWR.

Bartholomeus, R. P., A. H. Van Loon and M. H. J. Van Huijgevoort (2018). Hergebruik van industrieel restwater voor de watervoorziening van de landbouw - Praktijkproef subirrigatie met gezuiverd restwater van Bavaria. KWR 2018.089. Nieuwegein, KWR.

Bigah, Y., A. N. Rousseau and S. J. Gumiere (2019). Development of a steady-state model to predict daily water table depth and root zone soil matric potential of a cranberry field with a subirrigation system. Agricultural Water Management **213**: 1016-1027.

Dingemans, M., R. Bartholomeus and G. Medema (2018). Evaluation of the proposed EU regulation on minimum requirements for water reuse for irrigation. KWR 2018.075.

Doherty, J. (2010). PEST: Model independent parameter estimation, Watermark Numer. Comput., Brisbane, Queensland, Australia.

Kroes, J. G., J. C. Van Dam, P. Groenendijk, R. F. A. Hendriks and C. M. J. Jacobs (2009). SWAP version 3.2, Theory description and user manual. Wageningen, Wageningen University and Research Centre.

Matching agricultural freshwater supply and demand

Using recycled water for subirrigation purposes

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Gé van den Eertwegh (KnowH$_2$O)

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KnowH2O
Advies, Innovatie en Verbinding in Water

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Interreg
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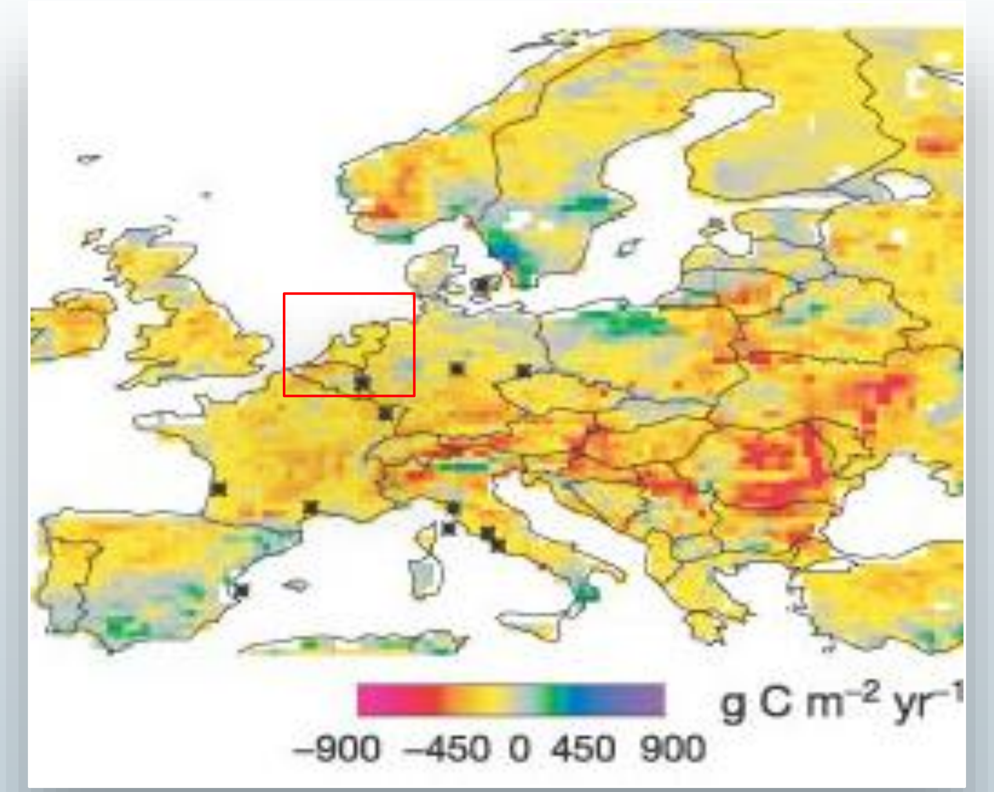
F2AGRI

Climate, water and agriculture

Droughts in Europe affect crop production

REDUCED CROP PRIMARY PRODUCTIVITY IN EUROPE IN 2003 (CIAIS ET AL, 2005)

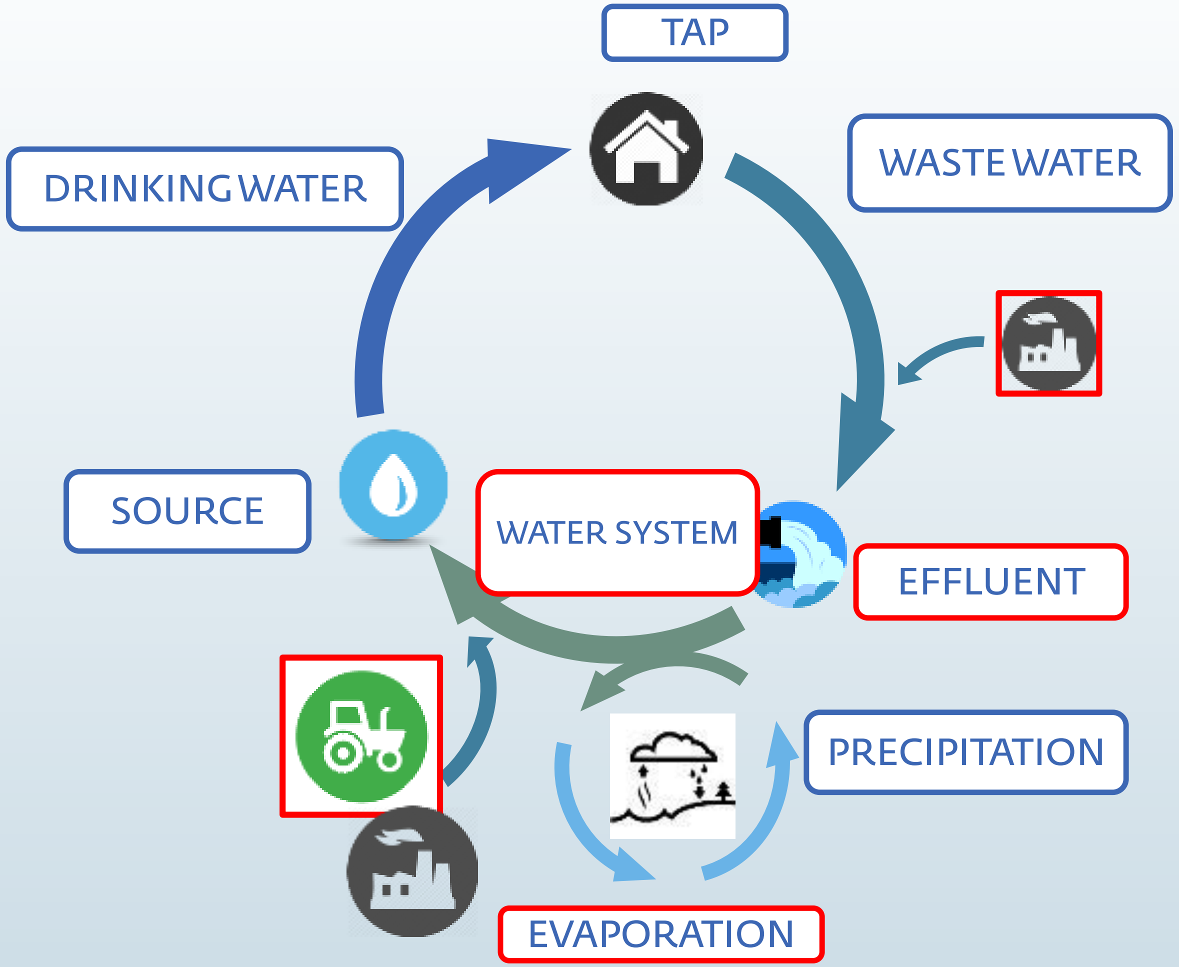


HIGH AND LOW GROUNDS IN THE NETHERLANDS
(RWS 2011, WATER MANAGEMENT IN THE NETHERLANDS)

Freshwater availability not sufficient to meet the demand

Make better use of available freshwater resources

- Wastewater quickly discharged via surface waters towards sea
- Farmers and water management authorities search for opportunities to manage risks of decreasing crop yields
- Exploit wastewater to balance regional water supply and agricultural water demand



WATER IN THE CIRCULAR ECONOMY (WICE)

Agricultural water supply

Active supply through subsurface irrigation

- Water supply through controlled drainage system
- Goal: raise groundwater level for optimal soil moisture availability
- Success depends on continuous water supply:
  - Industrial wastewater treatment plants → Bavaria Brewery
  - Domestic wastewater treatment plants→ Haaksbergen
  - …

SOURCE: AGROBEHEERCENTRUM ECO2 (YOUTUBE)

Interreg
Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling

Bavaria Brewery

Testing sub-irrigation with industrial wastewater on dry field

- Groundwater use: 2.5 Mm^3/y
- Located in agricultural area: drought
- Wastewater: 1.5 Mm^3/y discharged via surface water
- Bavaria: reuse wastewater for agricultural water supply

Monitoring sub-irrigation experiment

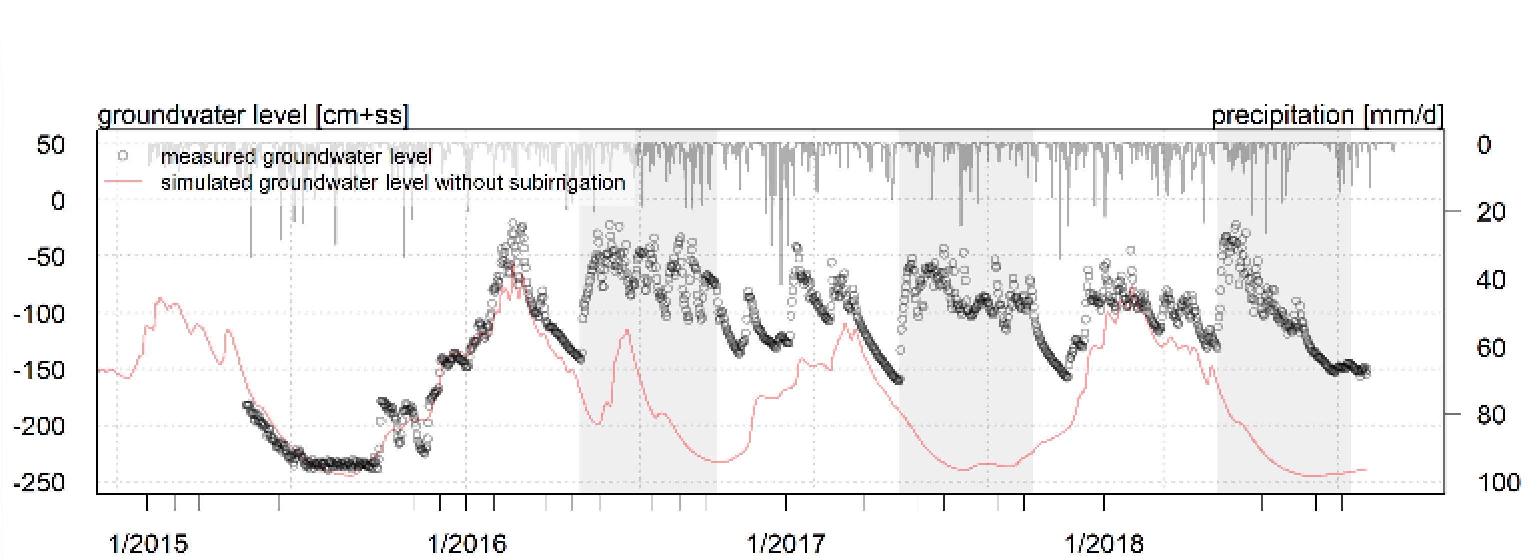
Effect sub-irrigation on groundwater level

Measurements (selection):

- Groundwater level: raised >1m due to sub-irrigation
- Soil moisture content: increased

Available water supply:

4100 m³/d → potentially enough to scale up from 8.5ha to 82ha



Sub-irrigation with treated domestic wastewater

Haaksbergen case

programma Lumbricus

Sub-irrigation with treated domestic wastewater

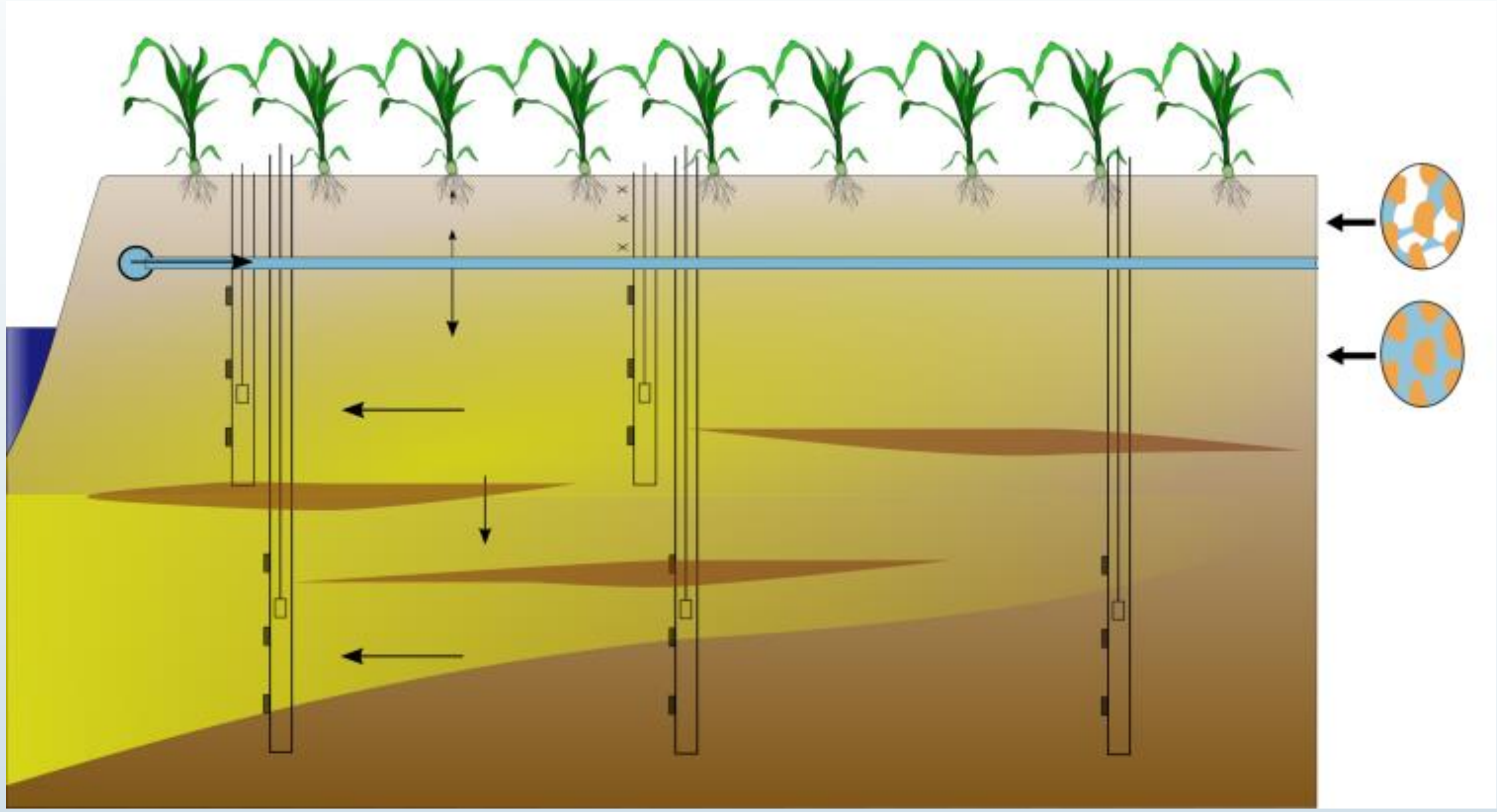
Water quality: focus on micro-pollutants

Measurements:

-Depth transects in both the unsaturated and saturated zone

-Tracer Cl:Br

-Remnants of pharmaceuticals



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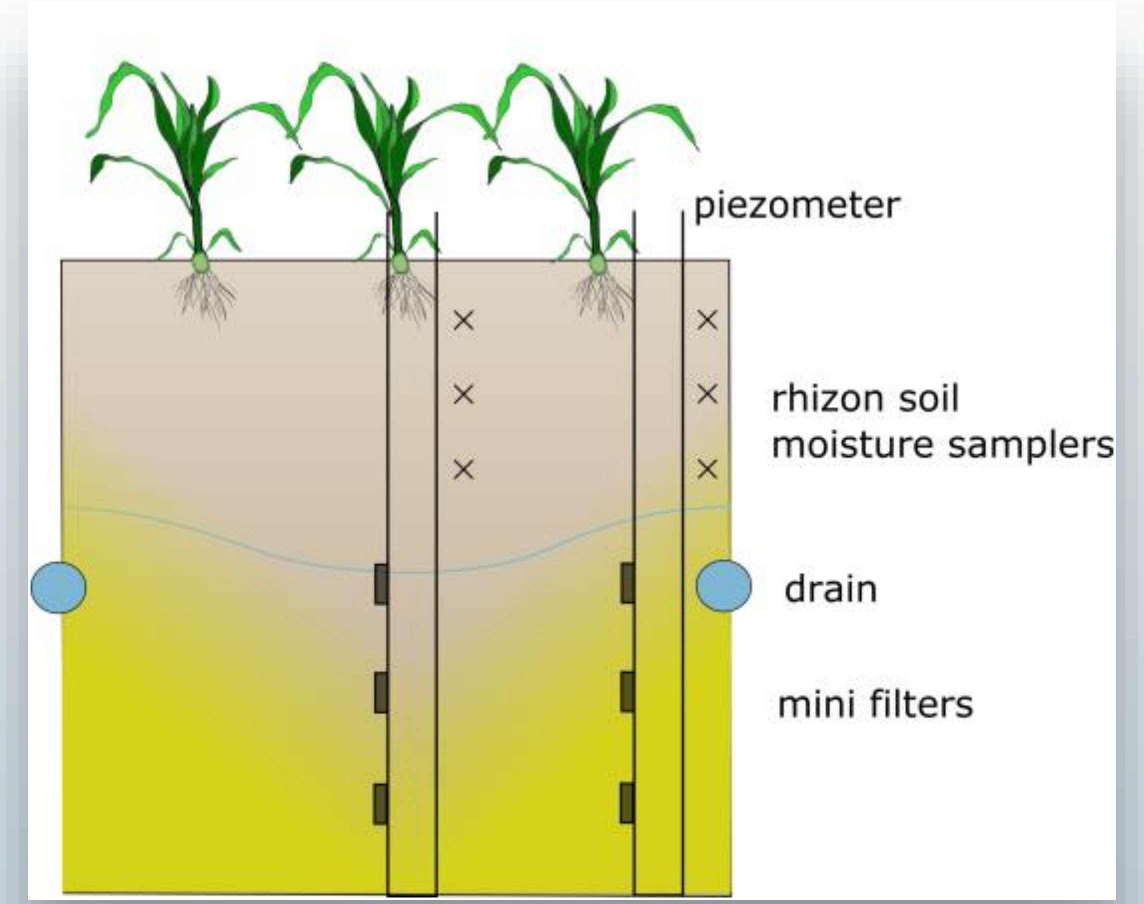

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Sub-irrigation with treated domestic wastewater

Water quantity

Water supply Haaksbergen:

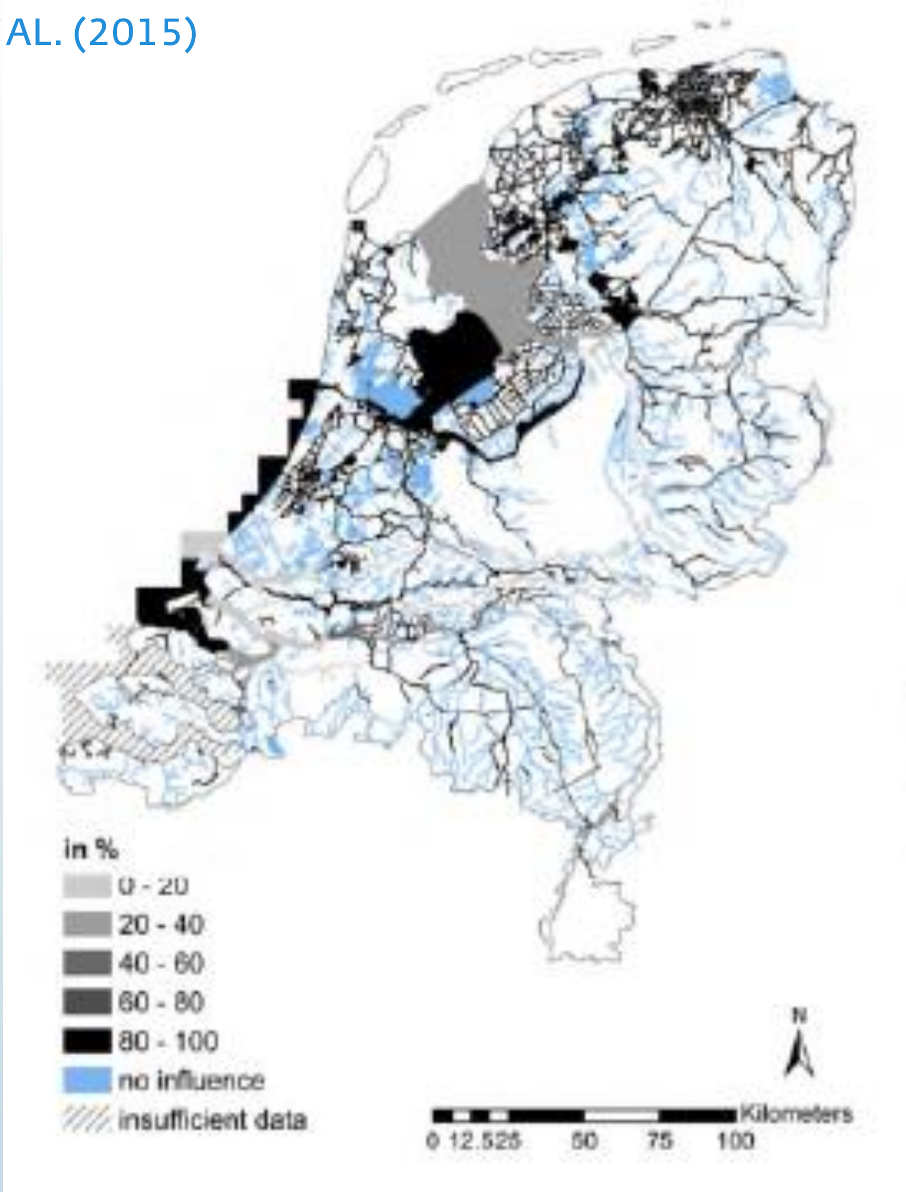
- 4 mm/d (220m^3/d)
- 3% of available effluent

Many more sources…

Indirect reuse of treated wastewater

Many surface waters affected by treated wastewater

COPPENS ET AL. (2015)



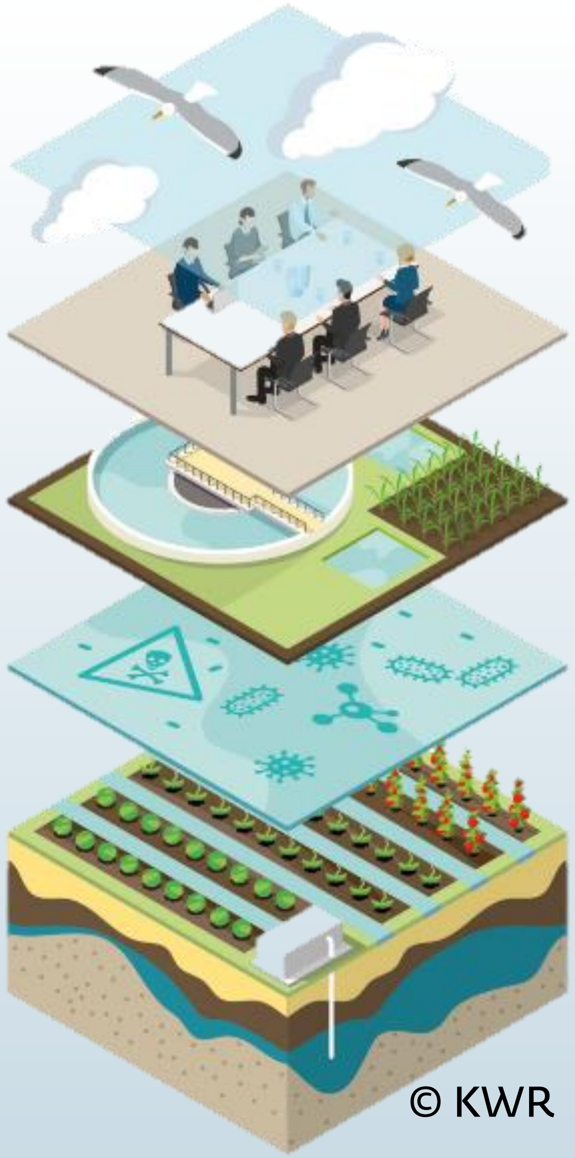
Matching agricultural freshwater supply and demand

Water reuse, a multi-layered approach

Agriculture will be confronted more and more with yield losses due to drought

The use of alternative freshwater sources, such as treated wastewater, can reduce drought damage. But is it safe?

Important role for industry in water management and climate adaptation!



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Sustainability and environment

Legislation and regulations

Water treatment technologies

Health and safety

Reuse in agriculture or industry

Subsurface water storage

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Patrick Smeets Sun. 14:20
Workshop: AquaNES QMRA-tool: a webtool for quantitative microbial risk assessment of water reuse applications

Klaasjan Raat Mon. 11:20, MOA 5
Aquifer storage and recovery to enable water reuse across sectors

Patrick Smeets Mon. 14:20, MOA 5
Safe wastewater reuse in the United Arab Emirates

Luuk de Waal Mon. 15:00. MOA 4
Poster. Enabling aquifer storage and recovery by high flowrate filtration

Ruud Bartholomeus Mon. 17:10, MOA 4
Matching agricultural water supply and demand using recycled water

Patrick Smeets Tue. 15:50, MOA 5
Literature review on pathogen reduction by water treatment processes

Kees Roest Wed. 15:00, MOA 3
CoRe Water: from WWTP to a sustainable water factory