Principles of Flow and Transport in Turfgrass Profiles, and Consequences for Management

Coen J. Ritsema and Louis W. Dekker
Alterra, P.O. Box 47, 6700 AA Wageningen
Netherlands

Jos van Dam
Wageningen Agricultural University
Nieuwe Kanaal 11, 6709 PA Wageningen
Netherlands

Klaas Oostindie
Alterra, P.O. Box 47, 6700 AA
Wageningen
Netherlands

Keywords: turfgrass hydrology, soil water repellency, preferential flow and transport, modelling

Abstract

Sport turfs require specific soil and water management strategies to achieve optimal sport turf performance and grass quality. In this study the know-how of flow and transport mechanisms in turfgrass porous media is highlighted under drought conditions when water repellency cause preferential flow. An illustration is given of the principles that cause soil water repellency and dry spots for the Ouddorp site in the Netherlands, and ways to prevent or alleviate dry spots. The concept of the critical soil water content is discussed and illustrated with field observations and with computer simulation results. Furthermore, an integrated monitoring and management system is proposed aiming at optimizing soil and water management strategies for sport turfgrass systems. The system is based on the integrated knowledge of soil profile characteristics, the actual soil water content status, and short-term weather expectations.

INTRODUCTION

Management of sport turfgrass systems is a complex matter, and requires up-to-date knowledge, sufficient technical equipment and an advanced decision support system to support the respective greenkeeper. Sport fields are often affected by either too wet or too dry playing conditions, causing the turfgrass quality to deteriorate. Especially, the effects of prolonged drying are poorly understood and need further attention to optimize the use and management of turfgrass media. With this respect, soil water repellency has received insufficient attention in the past, and currently it is acknowledged to be one of the most important processes affecting soils adversely under drying conditions (Ritsema and Dekker, 2000). Soil water repellency often leads to a loss of turfgrass quality (Fig. 1), and to irregular wetting and development of preferential flow paths, which might cause rapid transport of surface-applied agrochemicals to underlying groundwater systems. The aim of the present study is to investigate water flow and solute transport processes in the unsaturated zone of a water repellent sandy turfgrass system, with special attention to: i) monitoring the formation of preferential flow paths during successive rain events, and ii) the development and application of a new modelling approach for simulating flow and transport in turfgrass media.

MATERIALS AND METHODS

Soil Characteristics

Field experiments were carried out on a natural turfgrass system near Ouddorp, the Netherlands. The soil consisted of an approximately 100 mm thick organic-rich surface layer, on top of fine dune sand. Water repellency in the upper 500 mm of the Ouddorp soil was extremely high, and somewhat lower in the shallow surface layer. Deeper in the profile water repellency was absent (Dekker and Ritsema, 1994). The Ouddorp soil becomes water

1st IC on Turfgrass
Ed: P.A. Nektarios
Acta Hort. 661, ISHS 2004

repellent when dried to a certain extent, i.e. when water contents drop below the so-called critical soil water content (Ritsema et al., 1997a). In Fig. 2 the critical soil water content is shown versus depth for the Ouddorp soil, and defines the conditions under which, the soil is wettable or water repellent, and when uniform or preferential flow occurs.

TDR Measurements

An automated TDR device has been used to measure volumetric water contents of the soil within a 2 m long and 0.7 m deep vertical transect (Ritsema et al., 1997b). The probes were placed 150 mm apart in the horizontal direction at depths of 40, 120, 200, 300, 400, 550 and 700 mm. Every 3 h, the TDR device automatically started a measurement series, and, in total, measurements continued for around 8 months. Almost 200,000 volumetric soil water content values were recorded. These were used to construct two-dimensional water content distributions for every 3 h time-step. In all, around 2,000 graphs were made, a selection of which is presented in the present study.

Modelling Approach

The SWAP (Soil-Water-Atmosphere-Plant) model (Van Dam et al., 1997) was adapted to account for the effects of soil water repellency on flow and transport in order to make it applicable for sport turfgrass systems (Fig. 3). One of the parameters introduced in the SWAP model to account for water repellency is the critical water content, θ_{crit} ($cm^3\ cm^{-3}$) which changes with soil depth. As long as the soil water content θ is larger than θ_{crit} for each soil depth, the water flow is calculated similar to ordinary dynamic flow in a uniform, layered soil profile. In such conditions Richards' soil water flow equation is solved for the integral soil profile with a robust implicit numerical scheme (Van Dam and Feddes, 2000). In case θ becomes smaller than the specified θ_{crit} at a certain soil depth, the preferential flow paths are formed. Three zones in the soil profile are then distinguished (Fig. 4): a distribution zone, a finger zone and a redistribution zone. The distribution zone extends from the soil surface until the water repellent region with $\theta < \theta_{crit}$. At the soil surface the usual top boundary conditions apply, whereas at the interface with the water repellent region a zero flux condition is inserted. As long as unsaturated conditions occur in the distribution zone, the soil water flow will be vertical. However, when the soil at the bottom of the distribution zone becomes saturated, lateral flow towards the fingers starts. Numerically this is accomplished by imposing $h = 0$ if h tends would exceed zero and calculating the soil water flux q_{fing} by solving the Richards' equation for each soil compartment.

The finger zone stretches from the top of the water repellent region with $\theta < \theta_{crit}$ until the soil depth where the soil water pressure head h becomes equal to a prescribed critical pressure head h_{fing}. We assume that for $h > h_{fing}$ the fingers gradually disappear due to divergence of flow lines. This depth therefore depends on the drainage situation. For instance in case of a shallow groundwater level, the bottom of the finger zone will be fluctuating with the groundwater level (Fig. 4). The soil water flow inside the fingers is again solved with the Richards' equation. The top boundary condition of the finger zone is a flux condition with $q = q_{fing}$. The bottom boundary condition of the finger zone is a head condition with $h = h_{fing}$, while SWAP calculates the upward or downward soil water flux. Lateral water flow from the fingers to the water repellent soil is neglected because the finger will not expand due to water repellency and hysteresis. As long as q_{fing} increases, the relative cross section A_{fing} ($cm^2\ cm^{-2}$) is derived from (Selker et al., 1996):

$$A_{fing} = \frac{q_{fing}}{K_{sat}}$$

where K_{sat} is the saturated hydraulic conductivity ($cm\ d^{-1}$). This relation implies that nearly saturated conditions occur in the fingers. However when with time q_{fing} becomes smaller, the relative cross section remains constant and the water contents in the fingers decrease. Only when in a prolonged dry period the critical water content in the fingers is reached, A_{fing} is reset to a specified minimum relative cross section.

Soil water flow in the water repellent region of the finger zone and in the redistribution zone is solved simultaneously with the Richards' equation, taking into account the relative cross section of the water repellent region. At the top a zero flux boundary condition applies, while at the bottom the usual bottom boundary conditions of SWAP apply. The upward or downward flux at the bottom of the fingers is included as a sink or source to the Richards' equation.

The fingers may disappear when in the water repellent region θ becomes larger than θ_{crit} or when the cross section of the fingers becomes larger than a preset maximum. In that case the Richards' equation applies.

RESULTS AND DISCUSSION

TDR Measurements

In order to illustrate the process of preferential flow path formation and recurrence, a selection was made of two pronounced rainy periods. For each rainy period, the soil water content distributions measured within the TDR transect are shown just before, during (twice), and at the end (or after cessation) of the rainfall (Fig. 5). Volumetric soil water contents before the rain events (Fig. 5, left hand side) were generally below 10% for the water repellent subsoil, and up to 10% to 25% for the organic-rich surface layer, although there were some differences. No preferential flow patterns were present before the start of the rain events, but these emerged during both rainy periods. The preferential flow paths protruded through the water repellent layer and reached depths of around 600 to 700 mm. Observed patterns indicated that preferential flow paths recur at the same locations during successive rain events, due to the hysteretic water retention character of the Ouddorp sand.

Model Application

The adapted SWAP model has been used to simulate non-reactive transport through the Ouddorp experimental field. As an example, Fig. 6 shows bromide concentration – depth profiles simulated with both the traditional and adapted SWAP versions, using uniform and preferential flow conditions, respectively. Computed transport of bromide for the water repellent soil is much faster in case the adapted SWAP model has been used, i.e., in case preferential flow is taken into consideration. In the situation of transport of reactive compounds, also the total receiving dose at a specific depth will be much higher compared with uniform flow because large parts of the unsaturated zone will be bypassed by the preferentially infiltrating water, reducing the potential neutralizing capacity of the soil significantly.

Consequences for Management

Best management practice for sport fields and turfgrass systems should aim at preventing the porous media to become water repellent. When water repellency develops, it is extremely difficult to rewet the dry, water repellent soil pockets as water will by-pass these regions largely. Generally, regular surfactant applications will result in an improvement of the soil wettability, and at the same time will decrease the critical soil water content values in the long-term, as for instance recently shown by Dekker et al (2003). More strategically would be to implement a system which prevents soils to become water repellent. We feel that this can be achieved by combining regular surfactant treatments by a sophisticated irrigation scheduling system aiming at keeping the soil water contents above the critical levels below which water repellency is generated. To realise such, some basic information is needed about specific soil characteristics like the critical soil water contents values per depth, and real-time monitoring of the actual soil water content status of the soil at regular time intervals during the day. This type of information in combination with short-term actual weather predictions can act as input for a decision support system, based upon a simulation model like SWAP presented in this study, in order to accurately advice the greenkeeper with respect to irrigation scheduling and irrigation rates. Such a decision support system is currently not available commercially, but would be extremely beneficial for turfgrass and sport field greenkeepers. Fig. 7 shows results of a field trial with an arbitrary (2-weekly) and decision support based way of irrigating a turfgrass system susceptible to the formation of water repellency. The measured soil water contents in the left diagram (arbitrary irrigation) indicate that water contents drop regularly below the critical levels causing the soil to become water repellent. The diagram on the right hand side of Fig. 7 shows that occurrence of water repellency can be prevented by timely accurate irrigation. This appears to be a promising way to further optimize the management and overall quality of sport fields and turfgrass systems worldwide.

ACKNOWLEDGEMENTS

This work has been executed within the framework of Contract FAIR6-CT98-4027, financed by the European Commission and the Netherlands Ministry of Agriculture, Nature Management, and Fisheries.

Literature Cited

Dekker, L.W. and Ritsema, C.J. 1994. How water moves in a water repellent sandy soil. I. Potential and actual water repellency. Water Resour. Res. 30:2507-2517.

Dekker, L.W., Oostindie, K., Kostka, S.J. and Ritsema, C.J. 2003. Treating water repellent surface layer with surfactant. In: C.J. Ritsema and L.W. Dekker (eds.), Soil Water Repellency – Occurrence, Consequences and Amelioration. Chapter 26, pp. 281-289.

Nieber, J.L. 1996. Modeling finger development and persistence in initially dry porous media. Geoderma 70:207-230.

Ritsema, C.J. and Dekker, L.W. (Eds.) 2000. Special issue: Water Repellency in Soils. J. Hydr. 231-232, pp. 450.

Ritsema, C.J., Dekker, L.W., Hendrickx, J.M.H. and Hamminga, W. 1993. Preferential flow mechanism in a water repellent sandy soil. Water Resour. Res. 29:2183-2193.

Ritsema, C.J., Dekker, L.W. and Heijs, A.W.J. 1997a. Three-dimensional fingered flow patterns in a water repellent sandy field soil. Soil Sci. 162:79-90.

Ritsema, C.J., Dekker, L.W., van den Elsen, E.G.M., Oostindie, K., Nieber, J.L. and Steenhuis, T.S. 1997b. Recurring fingered flow pathways in a water repellent sandy field soil. Hydrology and Earth System Sciences 4:777-786.

Ritsema, C.J., Dekker, L.W., Nieber, J.L. and Steenhuis, T.S. 1998. Modeling and field evidence of finger formation and finger recurrence in a water repellent sandy soil. Water Resour. Res. 34:555-567.

Selker, J.S., Steenhuis, T.S. and Parlange, J.-Y. 1991. Estimation of loading via fingered flow. In: W.F. Ritter (ed.), Irrigation and Drainage: Conference Proceedings; July 22-26, Honolulu, Hawaii, USA, pp. 81-87.

Selker, J.S., Steenhuis, T.S. and Parlange, J.-Y. 1996. An engineering approach to fingered vadose pollutant transport. Geoderma 70:197-206.

Van Dam, J.C. and Feddes, R.A. 2000. Numerical simulation of infiltration, evaporation and shallow groundwater levels with the Richards' equation. J. Hydrol. 233:72-85.

Van Dam, J.C., Huygen, J., Wesseling, J.G., Feddes, R.A., Kabat, P., van Walsum, P.E.V., Groenendijk, P. and van Diepen, C.A. 1997. Theory of SWAP version 2.0. – Simulation of water flow, solute transport and plant growth in the Soil-Water-Atmosphere-Plant environment. Tech. Doc. 45, DLO Winand Staring Centre, Wageningen, Netherlands. pp. 167.

Figures

Fig. 1. Loss of turfgrass quality due to soil water repellency.

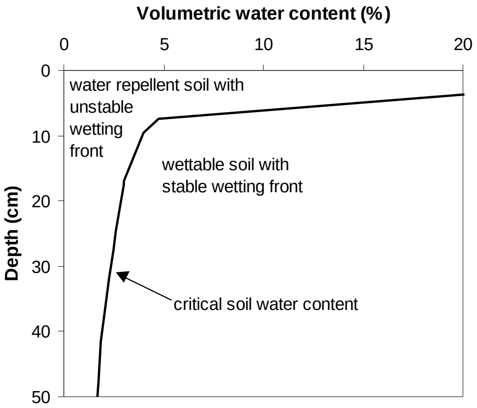

Fig. 2. Critical soil water content versus depth for the Ouddorp turfgrass system. In the zone left to the critical soil water contents, the soil is water repellent resulting in the formation of preferential flow paths during infiltration events. At higher soil water contents, the soil is wettable with uniform flow behaviour.

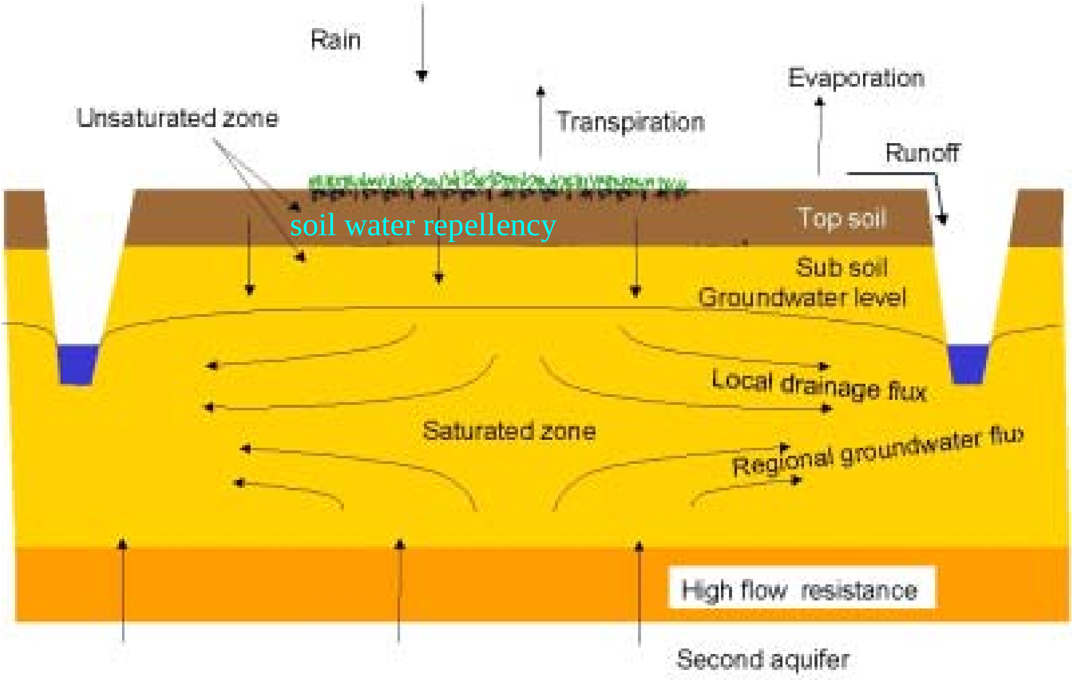

Fig. 3. Processes included in the SWAP (Soil-Water-Atmosphere-Plant) model.

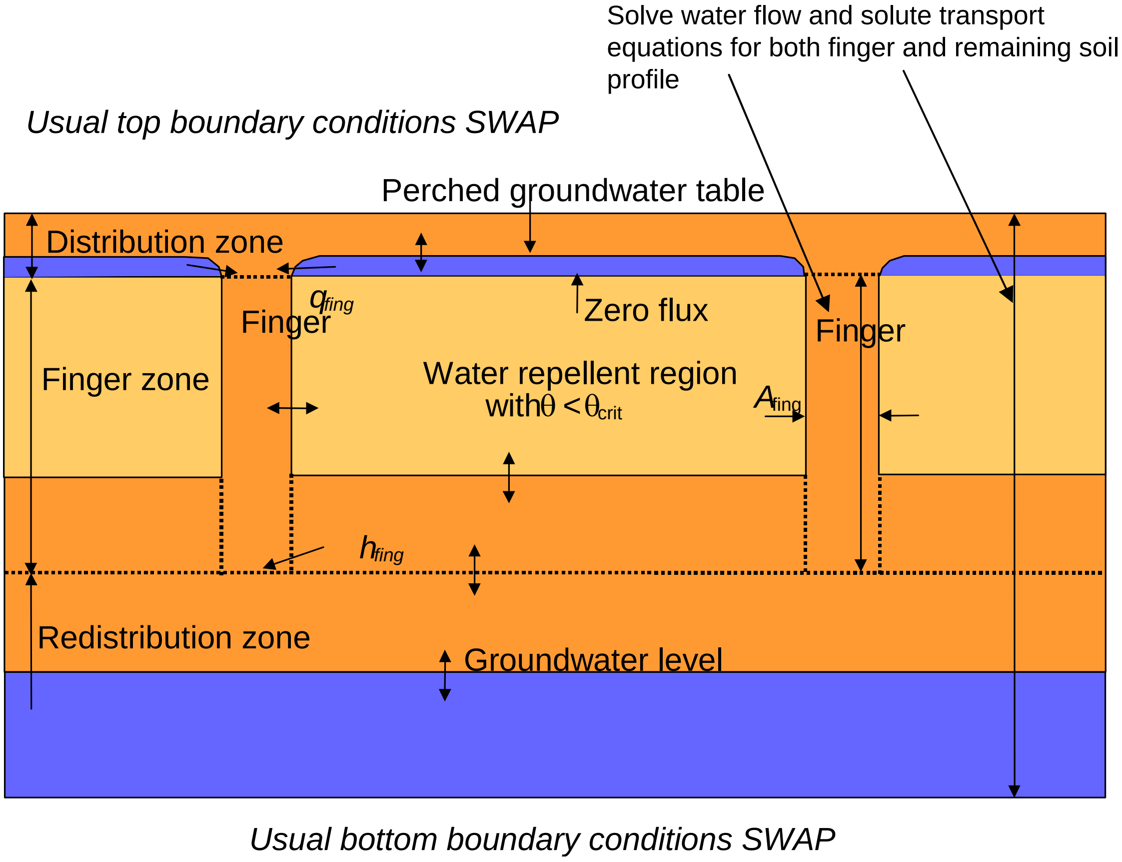

Fig. 4. SWAP flow concept for water repellent soils.

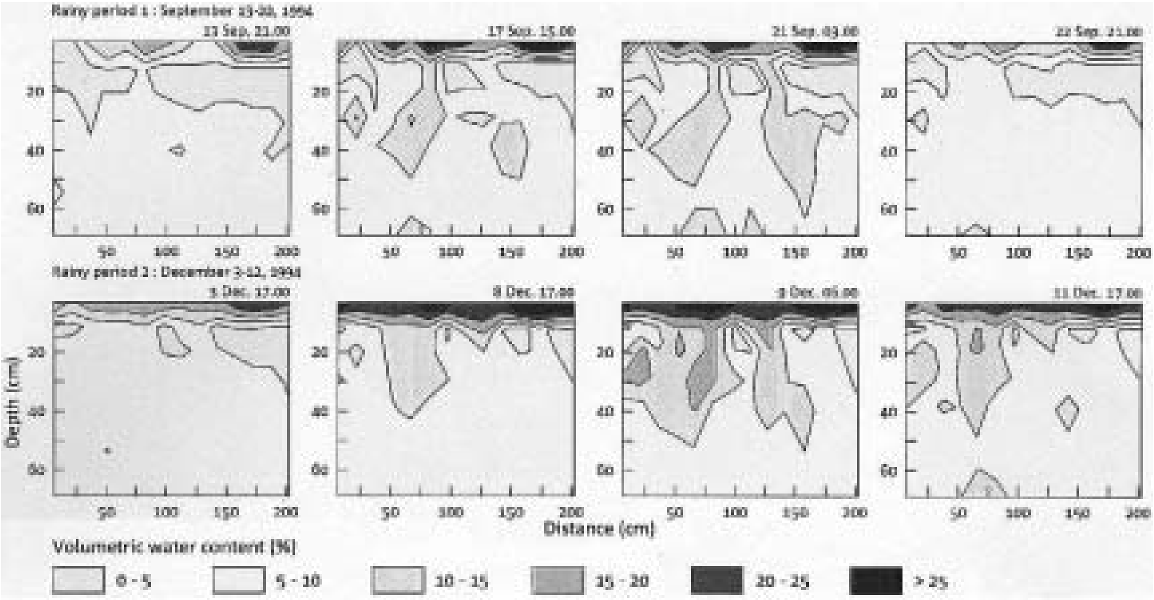

Fig. 5. Spatial distributions of soil water content in the 2 m long and 0.7 m deep TDR trench before, during and after the rainy periods selected.

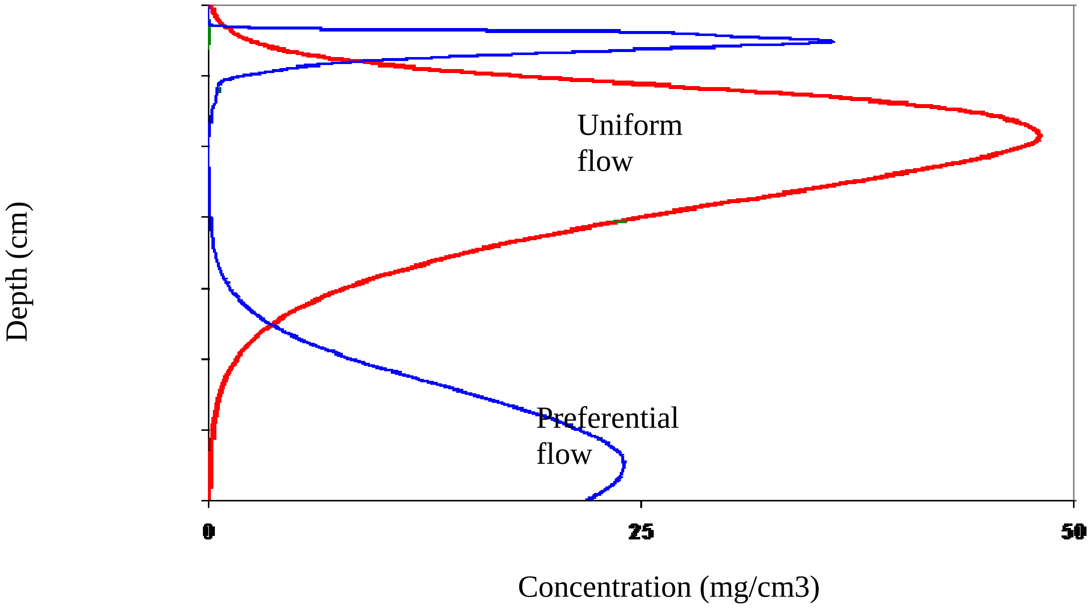

Fig. 6. Computed concentration-depth profiles for uniform (wettable soil) and preferential flow (water repellent soil) conditions using the traditional and adapted SWAP model, respectively.

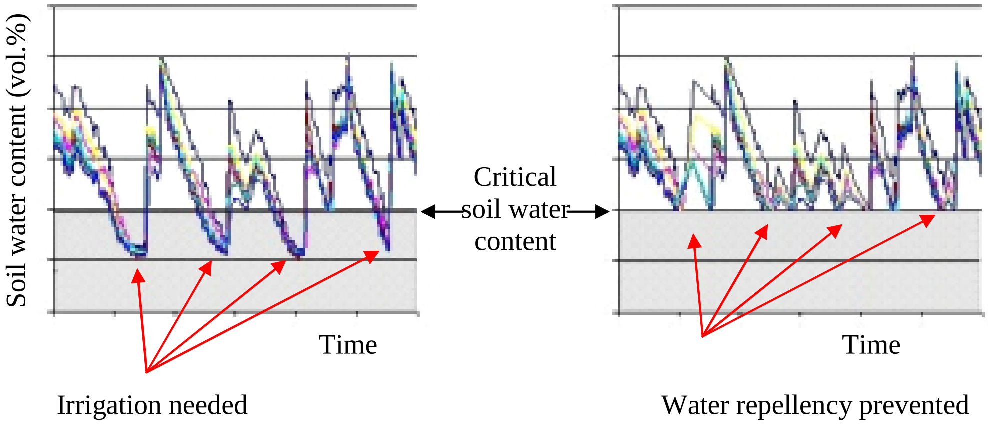

Fig. 7. Monitored soil water contents in the turfgrass system of Ouddorp under arbitrary (left diagram) and a decision support based way of irrigating (right). The latter systems prevents the soil to become water repellent.