Preserving Water Quality in Agriculture: Biobed Rotation to Vertical

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PRESERVING WATER QUALITY IN AGRICULTURE: BIOBED ROTATION TO VERTICAL

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ABSTRACT

Up to 95% of the contamination of surface water by pesticides comes from on-farm point sources in connection with washing and preparation operations. This contamination is a growing concern for environment and human health. Because of their efficiency, their low cost and their friendly and simple use, Biobeds were recognized as the best tool to treat these pesticide effluents. Assuming a single passage of the effluent through the Biobed followed by release of the percolate, the research focused on the efficiency of the depuration after a single percolation. Accounting for unknown hazards such as metabolites and bound residues leads, however, local rules in Europe to enjoin a recycling of the effluent until full evaporation to prevent any release in the environment. Managed as such, we show that the Biobeds are waterlogged and no longer perform the elimination of the effluent. This induces large hazards of either direct volatilization or effluent release, and goes with increased costs, dissatisfaction or demotivation of the farmers, thus jeopardizing the development of this solution. Accounting for these new depuration conditions leads to a new Biobed paradigm, namely optimization of the transpiration of the water rather than optimization of the single percolation depuration, which leads to sharp changes in Biobed forms, content and management. Moreover, the corresponding new system shows larger performance, decreased space and maintenance requirements, and improved aesthetics. This is shown in the present study based on compared monitoring of the systems performance, hydrodynamics and substrate conditions during use.

INTRODUCTION

Water pollution by pesticides is an increasing problem in most countries. Pesticides (fungicides, insecticides and herbicides) are detected in any surface and ground waters of the earth, including oceans and polar snow. Furthermore, pesticides are suspected to be cause of the increasing number of cancer cases and forms, and increasing incidence of neurodegenerative diseases [1]. In Switzerland, pesticides load sometimes reach several micrograms per litre in the rivers during pesticide application periods [2, 3].
Agricultural pesticides contaminate surface and ground waters *via* two main pathways: diffuse pollution and point source pollution. From 40 to 90% of pesticide pollutants come from point sources and are linked to accidents and leaks during handling operations, storage of pesticides and the washing of apparatus [4, 5]. The corresponding effluents are usually discharged in farm runoff or in sewage collectors, and most of this pesticide load will not be degraded [5] and will contaminate the natural surface waters. To mitigate this point source pollution, on farm treatment is required. Several systems can be used: the effluent may be burned, dried, coagulated and flocculated then filtered on different matrices, and degraded chemically or biologically [4]. Several of theses processes are licensed in Europe. In Switzerland, for the moment, none of them is allowed by public rules. Published studies conducted in different countries (Sweden, United Kingdom, France and Belgium) stress out the potential of Biobeds

[6, 7]. Biobeds are systems filled with soil based substrates reclaimed with organic materials, vegetated or not, on which are infiltrated the pesticide contaminated effluents. Pesticides are both immobilized in the substrate and degraded by the soil microorganisms, with satisfying reported cleaning performances. These systems are particularly interesting because they are economic, robust and easy to install in most farms. Original Biobeds were opened, that is to say that after infiltration through the substrate, effluents are spread on a meadow, used to prepare new treatments ore released as waste water. As a consequence, all the literature on Biobed functioning and optimization is dedicated to either the substrate composition or the microbial activity allowing for the best effluent depuration after a single percolation of the effluent (e.g. [8-10]). Note that there are no reported results on analysed metabolites in the percolate in these publications.
Biobeds can be closed [11] which means that the effluent is recycled through the substrate until full evaporation is performed before the end of the season. This is compulsory when the local laws do not allow for any release, which is the case in Switzerland. The corresponding Biobeds, however, have the same characteristics (substrate and dimensions) as the opened ones, they have not been optimized to the new major requirement: evaporation of water. The evaporation surface is on the top, and full evaporation of the effluents require a large surface area which is often not available. To minimize the size, irrigation must be intensified potentially leading to a water logging hazard for substrates. This should be carefully prevented since (i) most of the microorganisms degrading pesticides are aerobic and (ii) a free effluent layer at the bottom of the surface may induce direct volatilization of pesticides.

In the present study, we analysed the impact of the geometry of closed Biobeds on hydrodynamics, water logging, and cleaning and evaporation performances. We tested two different conditions and three mini Biobed systems (6 treatments), namely conditions with our without the protection of a roof against direct rainfall, closed Biobed with and without vegetation, and a new vertical greened Biobed.

MATERIALS AND METHODS

Experimental Biobeds

The Biobeds were made of 600 l containers filled with 500 l of substrate (described below). The vertical greened Biobed (VG-Biobed®) was made of a metallic structure of 1x1x0.25 m filled with 200 l of the same substrate (Figure 1). They were equipped with an automated irrigation system and a drainage system allowing recycling of the effluent *via* a tank. Two Biobeds were vegetated with a mixture of grass and clover and two remained with bare substrate; the VG-Biobeds were vegetated with grass and clover.

The substrate was a 30% (vol.) straw (5-15 cm long) and 70% soil mixture. The soil comes from the horticulture centre of Lullier (near Geneva) and contained: 43% silt; 36% sand and 21% clay.

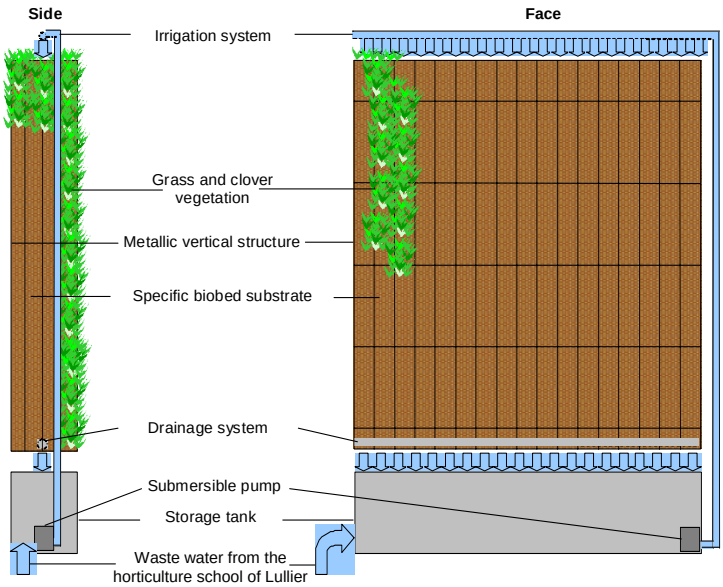

Figure 1: Layout of the VG-biobed

Methods

The level of the water in the drainage tank was used to monitor daily evaporation. After each irrigation cycle we measured the substrate temperature, pH, redox potential and matric potential. Climatic data (precipitation, temperature and wind) were recorded. The physical properties of the substrate were measured (hydraulic conductivity, porosity and pore size distribution). Conservative transfer experiments were performed with NaCl and reactive experiments were performed with Carbendazim® a fungicide and Diazinon® an insecticide, both injected at 0.002% (active molecule). The concentration of pesticides in the drainage water were analysed by LC-MS.

The different Biobeds were first irrigated 7 times a day during 5 to 20 minutes, thus applying about 280 l of effluent per day on each Biobed following currently recommended rates. After some weeks, the irrigation rates (number of irrigations and duration) were decreased until some wilting of the grass was observed.

RESULTS AND DISCUSSION

Evaporation rate of the Biobeds

We found no significant differences in evaporation or evapotranspiration rates per surface units between horticulture tunnel protected systems and non-protected systems (Figure 2). Summer 2009 was relatively dry with only 250 mm rainfall compared to 500 mm in summers 2007 and 2008. Rainfall may increase the effluent volume due to the interception surface hence requiring a roof protection. The interception surface of the VG-biobed is small and a roof is not necessary, as shown by the negligible impact of rain events on the water balance..

When reported to the exposed surface, evaporation and evapotranspiration rates were almost equal for all systems. Consequently, when reported to the area occupied on the floor by the system (vertical projection), the evapotranspiration rate of VG-biobeds where much larger. We show that VG-biobeds evaporation rates where up to 5 times larger than other Biobeds with 2 times less substrate (Figure 2).

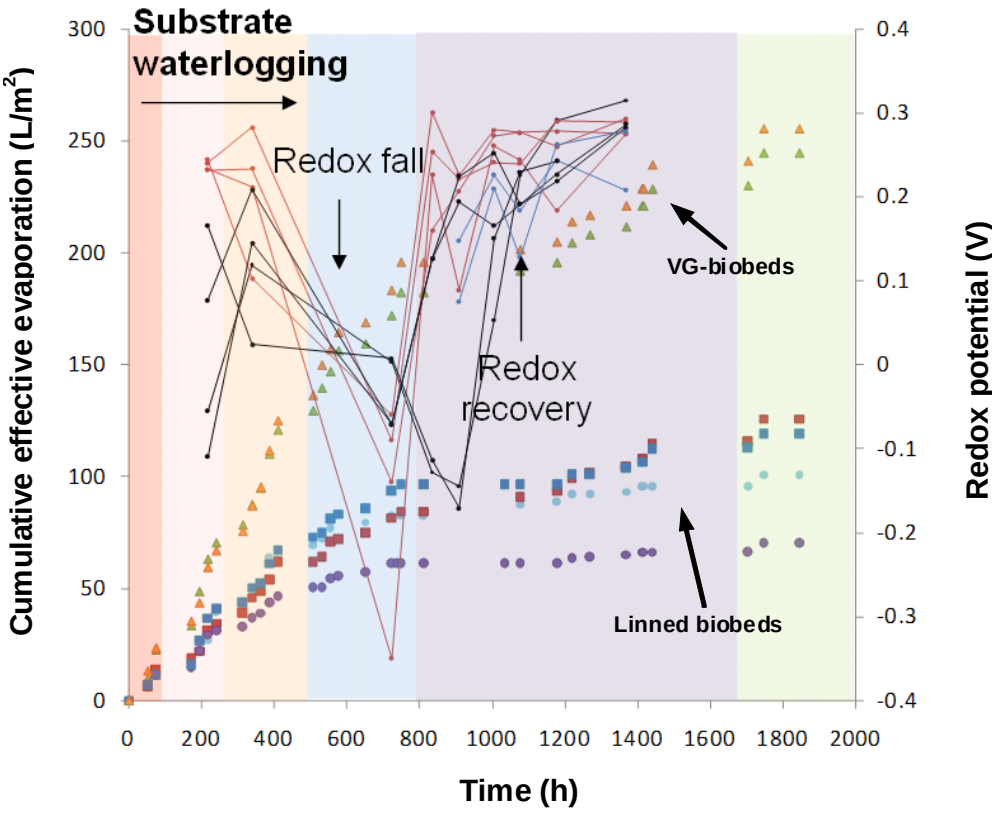

Figure 2: Cumulative effective evaporation (L/m^2) and redox potential (V) in relation with time (h) and different irrigation rates (red: 280 L/day; pink: 100 L/day; orange: 50 L/day; blue: 30 L/day; purple and green: 20 L/day) for the 6 tested biobeds.

Redox potential monitoring

The maximum evaporation rates are obtained with the larger irrigation rates per day (red and pink domains on Figure 2). This intensive irrigation, however, was cause to water logging of the substrate. The pH and redox potential measurements showed that reductive dissolution domain of goethite was reached in the Pourbaix diagram. We observed similar or larger reductive conditions for real size on farm systems (unpublished data). This is a consequence of the need to maximize effluent evaporation and minimize Biobed size, and should be prevented to ensure rhizospheric equilibrium for proper biodegradation of pesticides. We showed from microtensiometric measurements that the best irrigation rate was about 20 l/day (with 1 or more irrigation cycle – purple and green domains on Figure 2). This allowed the substrate to recover or keep oxidative conditions, a better plant health and thus good conditions for aerobic micro organisms. 30% of the structural porosity was occupied by air at this regime.

Reactive transfer and depuration in the substrates

The NaCl transfer experiments (breakthrough curves of the different Biobeds, not shown) allowed us to assess the reproducibility of the transfer experiments and showed the extent of

preferential flow through the Biobeds. Mass balances during transfer experiments were about 100% for the NaCl, which indicates no tracer loss. Preferential flow represented more than 30% of the flow for Biobeds and less than 10% for VG-Biobeds. Because the contact time between active molecules and substrate decreases with increasing preferential flow, the VG-Biobed results are much better.

Based on these results, reactive transfer experiments were performed on the VG-Biobeds only. The breakthrough curves of the reactive transfer experiments are presented in Figure 3 in a non-dimensional scale together with non reactive transfer results. We observed a drop of over 50% of the injected concentration for the two active molecules after the first irrigation cycle and the molecules concentration were below the detection level after the second irrigation cycle. This indicates that more than 50% of the active Carbendazim® and Diazinon® were retained in the substrate in a single percolation. Though they present different Kow, namely 643 for the Diazinon® (large affinity for soil) and 223 for Carbendazim® (moderate mobility), there was not a significant difference in their transport through this substrate. The observed retention is quite large and suggests potentially a good degradation by microorganisms.

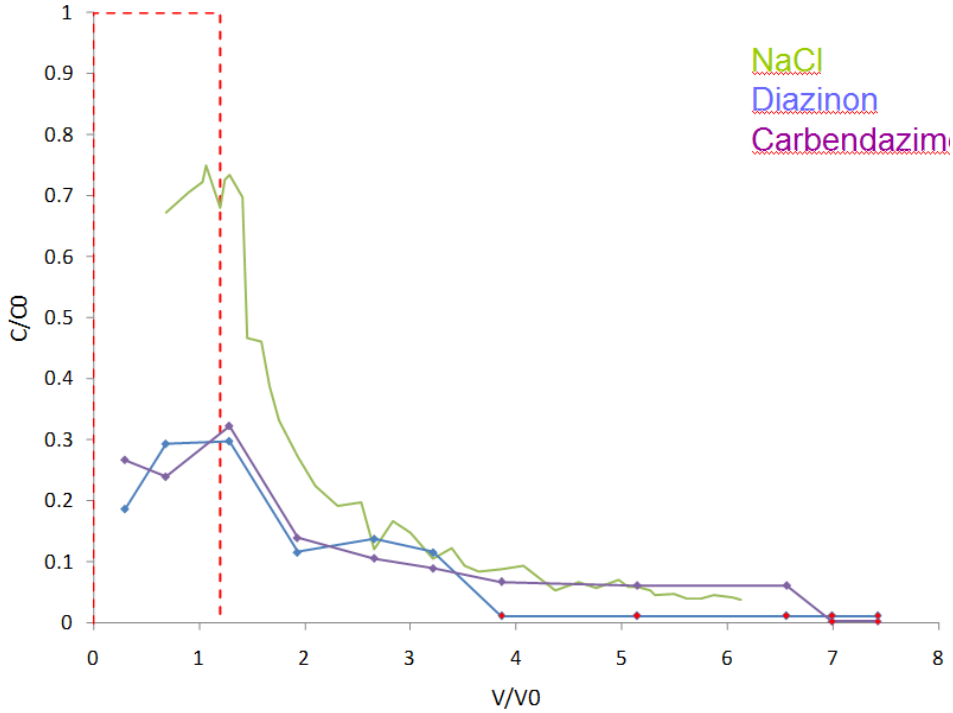

Figure 3: Breakthrough curves of NaCl (green), Diazinon® (blue) and Carbendazim® (purple) through the VG-biobed. C and C0 correspond to the measured and injected concentrations, respectively. V and V0 correspond to the effluent and poral volumes. The red rectangle corresponds to the injected solutions.

CONCLUSIONS

The relationship between substrate physical properties, irrigation regime, substrate geochemistry, and Biobed performance is poorly documented although their cleaning efficiency was recognized [11]. Practical experience suggest that minimizing Biobed size and maximizing Biobed performance may be a dramatic bottle neck issue leading to water logging of the substrate, and thus jeopardizing Biobed functioning. Indeed, Biobeds were designed in

the perspective of a single percolation of the effluent through the substrate, while the need to close the systems defines a new paradigm for research, namely maximizing the transpiration of the water.

We show that classical Biobeds, either with our without vegetation, must be waterlogged to ensure a high evaporation rate in the closed configuration, thus leading to poor depuration performance, substrate degradation and pesticide volatilization hazards.

The results obtained on the VG-biobeds are very promising since they solve these issues while improving overall efficiency: (1) VG-Biobeds require 10 times less soil surface for the same evaporation capacity; (2) they are protected from water logging because of vertical drainage, and vegetation with a strong root system allowing large evapotranspiration without excess irrigation, thus preventing direct volatilization of pesticides; (3) they do not need a protection from precipitation; (4) they can be piled to increase the volume of treated effluent and (5) they are aesthetic.

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