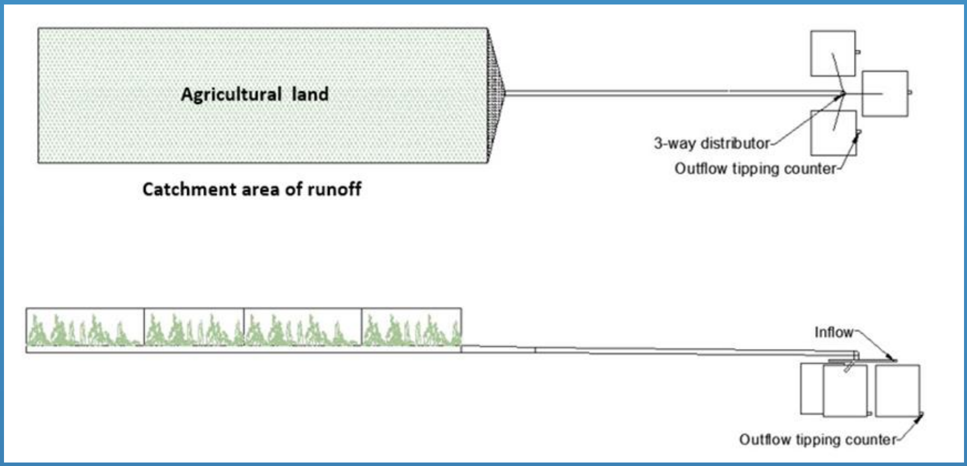
FACTSHEET

A BIO-INSPIRED MULTI-LAYER FILTER SYSTEM USING BIOCHAR ADSORBENTS FOR WATER AND NUTRIENT UPTAKE



Key information

The water treatment system is a multi-layered drainage system designed to retain water and nutrients from agricultural runoff (overland flow). It has been tested as an experimental prototype in the WATERAGRI project.

Target audience: future farmers, farm schools.

This project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No 858735.

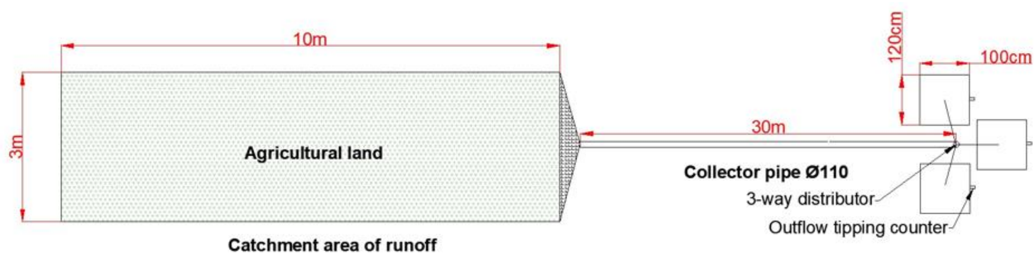
A. Brief Introduction:

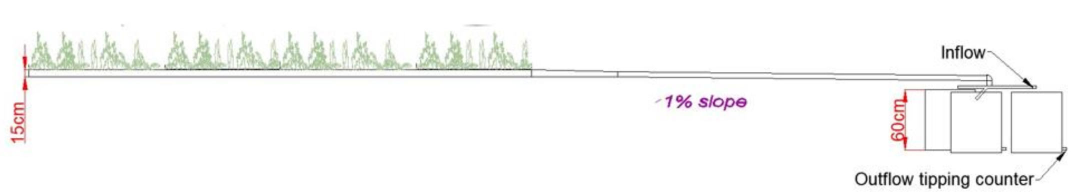
Alchemia-nova has in collaboration with BOKU developed a multi-layer vertical filter system to treat agricultural runoff. The drainage filter system consists of three IBC tanks (1.2 m2) cut on top installed in parallel and filled with different substrates to mimic a vertical flow filter system. The filters differed in terms of substrate used in the main layer and presence of vegetation: biochar/unvegetated, draingarden/vegetated, soil and vegetated, respectively. The bio-inspired filter was designed to work as a water retainer and a nutrient retainer addressing agricultural surface run-off and tested on the slope of an agricultural field in Mistelbach, Austria. This approach may result in economic value by re-using the saturated biochar as fertilizer and improving the soil structure, thus increasing long-term soil fertility. The system is expected to require little maintenance apart from harvesting the plants yearly and changing the biochar when it is saturated with nutrients.

B. Design concept and experimental set up:

Three vertical-flow multi-layer systems operating in parallel, were constructed above ground in three IBC tanks in June 2021, in an agriculture land in Mistelbach and received surface runoff from a 30 m2 cropped land having an inclination of 1% (Figure 1). Each system had a surface area of 1.2 m2 and 65 cm height composed of different layers of substrates. Filter 1: was unplanted filter (with biochar in the main layer); Filter 2: a vegetated filter system (with Draingarden® substrate + biochar). Filter 3: vegetated system with local soil as reference.

Surface agricultural run-off infiltrated vertically through the system (vertical flow) and outflow is measured with a tipping counter, connected to a PLC datalogger and PV panel. In terms of parameters measured: ammonia, nitrate, orthophosphate, pH, EC, temperature, soil moisture in two depths of the filter system, were monitored. The systems are designed according to the Austrian guideline for vertical flow wetlands ÖNORM 2505.





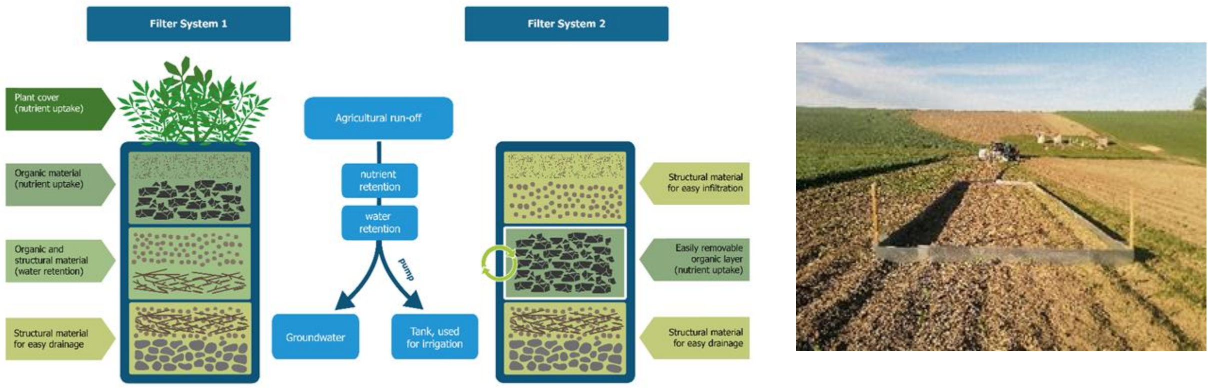


Figure 1 Drainage design (top), drainage filter system concept (left), and photo of the catchment area 26.05.2022 *(right)*

The long-term mean rainwater event-related 30-minute precipitation intensity of I30 = 48.3 mm/h was used as the basis for the design. Since the test field area is very small (30 m² - 3 m x 10 m), it was assumed that it contributes completely to the runoff event after only a short period of time. Therefore, a precipitation duration of 1 h was chosen, which results in a design precipitation (N) of 48.3 mm. A discharge coefficient (B) of 0.47 and a design precipitation (N) of 48.30 mm/h results in a drainage rate (QA) of 22.70 l/h*m² in relation to the experimental field or 48.30 l/h*m² related to the precipitation directly falling on the soil filter.

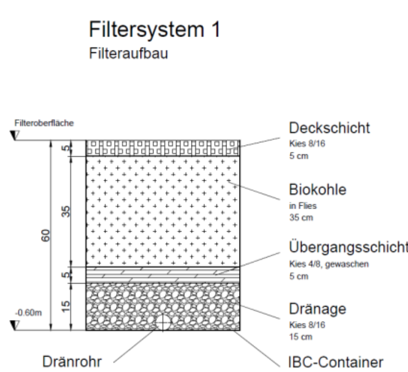
The filter surface area was assumed to be 0.8 m x 1.2 m and the catchment area of the field was therefore reduced to 10 m x 1 m per filter. After one hour, the runoff load (V) of the whole catchment is 1.45 m³. Putting the runoff load in relation to the filter surface, the calculated depth of runoff (h) is 508 mm or accordingly, a runoff rate (Q) of 0.14 l/s.

Regarding the selection of the layer thickness (Di), the design of a vertical flow soil filter according to ÖNORM B 2505 (2009) served as a rough blueprint.

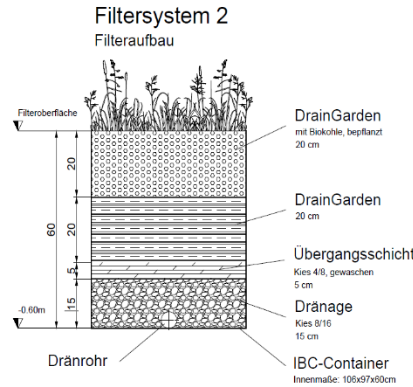
Table 1 Filter design details

BIOCHAR FILTER – LAYERS	LAYER DEPTH (cm)
Not Vegetated	no
Gravel 8-16 mm	12
MgOH coated biochar	30
Geotextile rabbit grille	-
Gravel 8-16 mm	20

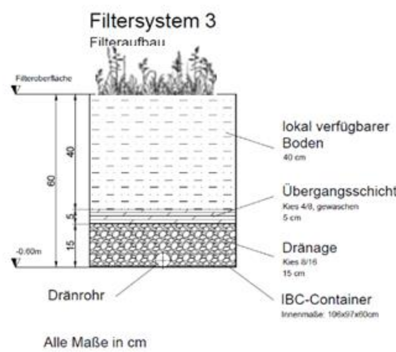
Note: Geotextile/rabbit grille (0.3m) was placed to easily remove the biochar.



DRAINGARDEN FILTER – LAYER COMPOSITION	LAYER DEPTH (cm)
Vegetated	yes
Draingarden substrate	20
Draingarden® substrate (fine, without compost) + 10 vol% coarse zeolite	20
Gravel 4-8 mm	5
gravel 8-16 mm	15



SOIL FILTER – LAYER COMPOSITION	LAYER DEPTH (cm)
Vegetated	yes
Soil (from the site)	40
Gravel 4-8 mm	5
Gravel 8-16 mm	15



C. Technical information:

Requirements for installation:

The system has not been tested in a full-scale setup. In the trial, the pipes that collect surface runoff from the end of the catchment area require rammed feet every 3 meters for stability. The 30 m long PVC collects the surface runoff, and a three-way distributor is used to divide the influent (surface runoff) on top of each filter system that operates in parallel. For the array of three filters, a three-way distributor is required to equally split the flow of the whole catchment to the three filters. It is important to clean and level the ground where the filters will stand to ensure homogenous water distribution and infiltration through the filter. When placing the pallets, a stable concrete slab should be placed beneath to distribute the weight better, especially on soft soil. The three-way distributor needs to be mounted on a stable pole which is previously rammed into the earth and then leveled for the proper division of the water flows. The PV island needs to face south, and more importantly, the batteries in a water and acid-proof container high enough not to get in contact with any runoff water (about 10 cm off the ground). Leveling of PV island is not very important as it is for the filters, but special care shall be taken in windy areas.

(iii) Requirements for operation and maintenance

The operation is automated and passively driven by gravitational forces (water catchment, distribution and discharge) and photovoltaic (monitoring and sensors). As with nature-based solutions, the plants need weeding every 30 days, but this is not vital to the reliability of the filtration system. The 3-way distributor also shows low maintenance, although this is heavily dependent on the water and sediments carried by the run-off. The wooden feet need to be condition-checked every 30 days for rotting processes. Except of the inlet, where sticks, stones or sediments can lead to clogging, the catchment area and piping are maintenance free.

(iv) Requirements for monitoring performance

Due the remoteness of the place a PV-island provides electrical power as well as shelter for monitoring equipment all on one pallet. The parameters measured were water outflow quantity, soil temperature and moisture. The measurements are triggered by a hydro switch inside of the pipe. This switch turns on once a 15cm long water film closes the contact between two poles and gives the start signal for measurement. The monitoring runs if there is a water flow (surface runoff resulting after a rain event) and stops 12h later if there is no more water.

In the trial tests, the monitoring of the filter system is carried out through

a) Probes to monitor soil moisture (Meter MAS-1) and temperature (PT1000) were installed at two level depths (17 cm and 30 cm for Filter 1, 2cm – 20 cm depth for Filter 2 and Filter 3 respectively.
b) Use of tipping counters (UGT 0.1 L Polycarbonate) in each filter system's outlet. Effluent samples collected are analysed in laboratory for PO_4-P, NO_3-N, NH_3-N, pH, EC, and temperature.

D. Costs and Benefits:

i. Cost of operation and maintenance. Fixed installation cost is €686 – €764 per system. However, upscaling requires an in-ground filter system; therefore, other cost estimations apply. The operation and maintenance costs of these pilot scale filter systems relate to the travel costs to the remote site and are usually higher than the cost to maintain the system with low requirements. Water analyses can also be considered to monitor the retention of nutrients in the filter.
ii. Farming benefits. The proposed system has the potential that if upscaled, may provide water retention capacity and nutrient recovery potential. The recovered nutrients (phosphorus, and nitrogen) can then be recycled by using the saturated biochar filter as fertilizer. Moreover, the system has the benefits of being a climate change adaptation approach in capturing agricultural surface runoff.
iii. Environmental and social consequences. In the medium to long term, better management of water resources in agriculture can contribute to the water security of the region´s ecosystems and communities.

E. Challenges and opportunities

i. Technical limitations (durability, slopes, soil and climate). The system assumes overland flow, so for the Austrian case the slope must ensure runoff with >0,1% as a point of reference depending on the runoff ratio of the soil (vegetation, type of soil, porosity, duration of rain event, etc.). Slopes between 1% and 5% are represented in the implementation of Mistelbach. Steeper slopes would require more practical evidence. The plowing direction determines the surficial hydrodynamic behaviour of the runoff and should be considered in the slope direction when planning a runoff filtration, but is limited by too high flow speeds and erosional forces. An economic dimensioning of the filters can cope with high-intensity rain events or light rain but cannot support long-lasting rain events due to storage capacity.

ii. Legal requirements. The setup in Mistelbach operated as small-scale above-ground filters show low environmental impact. An environmental assessment is needed at big scale implementation of the filters, especially when digging is required (subsurface installation) and the outlets are close to water bodies. The effluents leaving the system should not cause any environmental problems (high concentration of nutrients). In practice, the technical assessment of the extent of the contamination is naturally carried out by experts. The area type classification of the ÖWAV Rule Sheet No. 35 on rainwater treatment represents an important guideline.

iii. Evidence-base and uncertainties (TRL). The monitoring of effluent nutrient concentrations showed that the filters could be potential solutions, but careful selection of biochar should be made because they may have phosphorus in their composition that is leached at the initial stages of operation. Batch sorption experiments in Lab showed that the coated biochar retains phosphorus and nitrogen better at high inlet P and N concentrations, probably due to $Mg(OH)_2$ coating than at low phosphorus concentrations. Tracer tests with NaCl, revealed the systems had fast peaks indicating non-homogeneous flow behaviour. As stated in point E(i). technical limitations showed uncertainties in hydraulic behaviour at steeper slopes. The biochemical composition of the filter layers leave room for experimentation and for the interaction between layer thickness, medium composition, and economic investment as such. A subsurface implementation would show higher practicability for a larger scale application.

F. Reference and demonstration:

i. Public reports of WATERAGRI project:
   a. Deliverable 4.3 Description of the development of Drainage Solutions
   b. Deliveragle 4.5 Advanced Use of Biochar for Nutrient Retention
   c. Deliverable 4.7 Progress report on the development of the Nutrient

ii. Video link: https://www.youtube.com/watch?v=6LtD0pbzEkc

iii. Project website site: https://wateragri.eu/wateragri-solutions/

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