Prevent water contamination through point sources

TOPPS

Bio purification systems for spray remnants on farm

TOPPS

TOPPS is a 3-year, multi-stakeholder project covering 15 European countries – it stands for **T**raining the **O**perators to prevent **P**ollution from **P**oint **S**ources. TOPPS is funded under the **European Commission's Life program and by ECPA**, the European crop Protection Association.
TOPPS is aimed at identifying Best Management Practices and disseminating them through **advice, training** and **demonstrations** at a larger co-ordinated scale in Europe with the intention of reducing losses of plant protection products to water.

TOPPS started in November 2005 and ends October 2008.

For further information visit: www.TOPPS-life.org

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Content

Aim of the brochure

This brochure aims to inform farmers, advisors and authorities on possibilities to avoid contamination of surface water with Plant Protection Products (PPPs) through correct management of contaminated liquids during filling and cleaning processes of spray equipment on farm. The TOPPS project has defined Best Management Practices (BMPs) to avoid point source pollution with PPP and has addressed the management of contaminated liquids (remnants) as being a critical work process.
(Remnants: PPP-contaminated liquids resulting from residual volumes after first cleaning steps in the field, washing waters from cleaning, filling and maintenance operations on farm.)
In most countries involved the aspects of remnant management have not received the necessary focus and clear recommendations and/or regulations are missing. We are convinced that operators need clear recommendations on how to avoid PPPs entering raw water. General recommendations are insufficient and therefore with this brochure we intend to support the development of clear recommendations by sharing the experiences of experts from different countries.

1. Introduction to the operational context of bio purification systems

a. Water Framework Directive (WFD)

EU – Most Member States have already transposed the Water Framework Directive (WFD) 2000/60/EC into their national legislation. The objective is to improve and protect the status of all raw waters and the ultimate objective is to reach a minimum classification of 'good water status' for quality by the 3rd review period (2027).
From the Entry into Force in December 2003, the WFD provides a time-line which must be followed in order reach these objectives. Starting with an inventory (listing competent authorities, establish and characterise river basin districts), making monitoring operational, setting up river basin management plans – (RBMPs), for each district, reporting results, establishing measures to improve water quality and review them regularly (every 6 years).

The framework of the WFD includes so called Daughter Directives on Groundwater (2006/118/EC - which enters into force in January 2009) and surface water (EQS daughter directive on Environmental Quality Standards expected to enter into force mid 2010). These set targets for water quality standards in surface and ground water. Both raw water from groundwater or surface water are used for the production of drinking water in Europe. The drinking water standard is set at a level of 0,1 µg/l for PPP's (98/88/EC). This is equivalent to only 1 g of active ingredient in 10 million litres of water. The 0,1 µg/l is essentially a zero tolerance for PPP's in potable water. To help achieve these very stringent targets, specific local risk mitigation measures and the general and widespread adoption of BMPs are necessary. If PPP's exceed the 0,1 µg/l limit, even prior to any water treatment, Member States may decide to restrict or ban the respective products, which will lead to a loss of available options for the farmers to solve their crop production problems.

b. Entry routes of PPP's into water

I) Point Sources

Point sources are mainly concerned with the handling of PPPs. Key critical work processes are filling, cleaning and the management of remnants. Remnants are PPP contaminated liquids which may remain in the sprayer if not completely cleaned in the field, or created through spills / tank overflow at the filling on farm, or resulting through the cleaning of the inside and outside of the spray equipment on farm. Studies have shown that point sources represent 40 to 90 % of the entries of PPP's into water, being the most significant entry route.

II) Diffuse sources

Diffuse sources are mainly concerned with the application of the PPP's in the field. Key critical areas are runoff through erosion effects, entries through drainage systems and spray drift.

c. Bio purification systems

I) Principle

Bio purification systems treat PPP contaminated liquids on farm using adapted micro-organisms within an active substrate mixture to biologically degrade or breakdown PPPs. These systems can be self built and managed by farmers for their specific farm situation. However, incorrect dimensioning and management of these systems can seriously affect their efficiency. Therefore it is necessary to follow these guidelines carefully. Research has shown that bio purification systems can achieve purification from 95% to more than 99% in optimal conditions and for most PPPs. Figure 1 provides a general framework of a bio purification system. (De Wilde *et al.*, 2007).

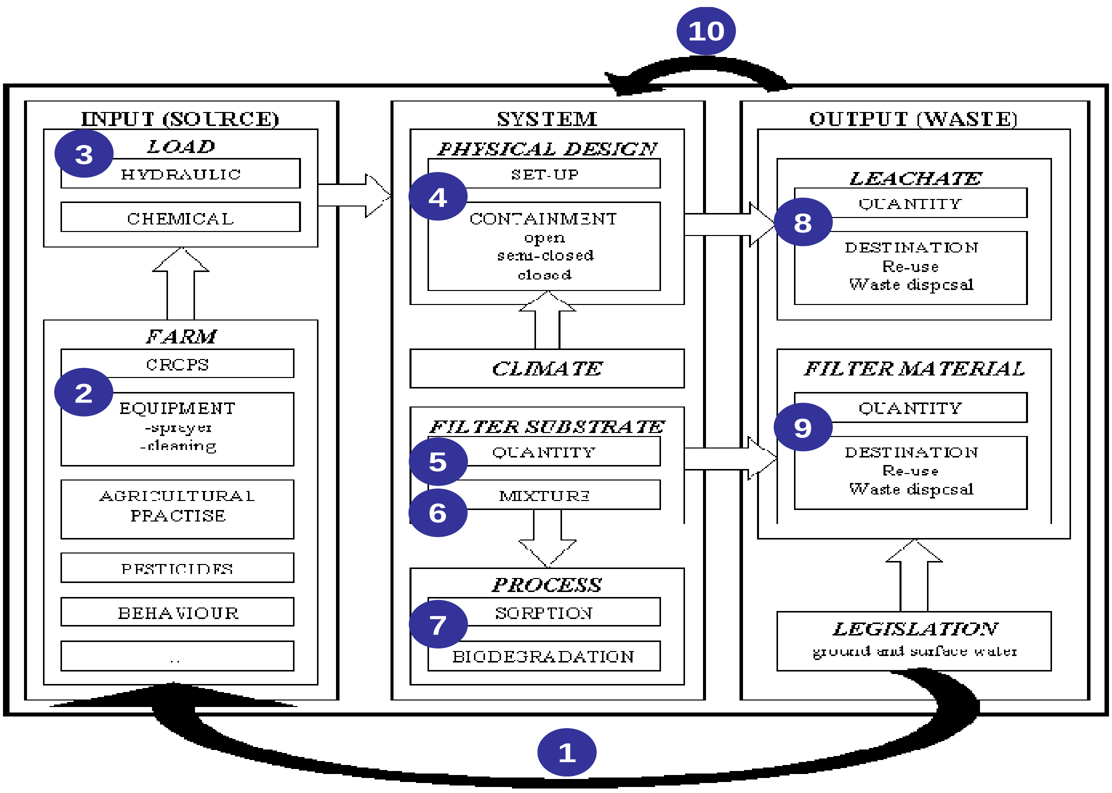

Fig. 1: Schematic overview of the operational context of bio purification systems (source: De Wilde et al. 2007 – numbers refer to text titles).

II) Biobed system

Biobeds are part of the dedicated areas for filling and cleaning of the sprayer. It is important to note that for using biobed systems it is strongly recommend that the sprayer is cleaned in the field and only the remaining diluted contaminated liquids which cannot be sprayed out or distributed evenly across fields are released onto the biobed. This will result in a much better purification, and the possibility to use smaller and cheaper system.

The biobed systems recommended (Torstensson *et al.*, 1997 & 2000; Basford *et al.*, 2004) should be lined to prevent any leaching of PPPs to groundwater. Basically these are either excavation in the ground or constructions above ground to collect and process contaminated liquids. The lined biobed is filled with an active substrate mixture of topsoil (containing the natural micro-organisms to break down PPPs) peat and straw.

Fig. 2: biobed (source: Visavi)

Fig. 3: Biobac (source: Mybatec)

Lining of biobeds should be done with impermeable materials like concrete or hard plastics, with an open surface on top. Lined biobed are closed systems, where the remaining leachate is collected and evaporated. In some regions biobeds are covered by grass which can further reduce the collected water through transpiration. In some regions biobeds are used as a direct filling and cleaning place with the sprayer parked on top (figure 2). Biobeds are mostly used in combination with a separate filling and cleaning place, from where the collected excess water is drained directly to the biobed or stored in a buffer tank to allow indirect charging onto the biobed (figure 3). In such setup, the contaminated liquids can be equally distributed over the total surface of the biobeds and spread throughout the year for an optimal and efficient use. In regions with higher rainfall or risk of storm overflow, it is recommended to cover the biobeds to prevent saturation and overflow of the biobed substrate with water. (Variations of the biobed themes exist: Currently unlined biobeds are also used in areas where intensity of spraying is very low and leaching is no risk, however the BMPs for new biobeds recommend lining of the biobed.)

Biobed systems generally consist of 10 to 30 m³ of active substrate mixture. They are mostly used on larger farms to treat the higher volumes of contaminated liquids generated but communities of smaller farms are also taken up shared facilities. Such a biobed is normally in use for 6 to 8 years and then the active substrate mixture needs to be replaced. General recommendation is to spread the resulting mixture with a manure spreader on a field at the farm. Such official recommendation to date exists only in very few countries. It is recommended to always check with local authorities which procedure is allowed.

III) Biofilter system

The principle of the biofilter is similar to the biobed. It is strongly recommend that the sprayer is cleaned in the field and only the remaining diluted contaminated liquids which cannot be sprayed over a field are released onto the biobed. This will result in a much better purification, and the possibility to use smaller and thus cheaper systems.

The biofilter (Pussemier *et al.*, 2004) is constructed out of 2 to 3 containers or Intermediate Bulk Carriers (IBCs) of 1m³ vertically stacked on each other and filled with a similar active substrate mixture as the biobeds (figure 4). The biofilter system can be modified (Debaer & Jaeken, 2006) with some additional horizontal units on the ground containing plants for additional purification and evaporation (figure 5). Biofilter systems are in general much smaller in size and have lower amounts of active filter substrate or biomix (2-5 m³) than a biobed. For processing higher water volumes, parallel biofilter systems are an option. The waste water is collected on a separate filling and cleaning place, and then pumped onto the top of the biofilter. Biofilters are open systems with possible remaining leachate being collected. This can be recycled by pumping it again onto the biofilter or after purification can be sprayed out in the field eg during application of a non

Fig.4: Biofilter (source: CRAw)

Fig.5: Modified biofilter (source: pcfruit)

selective herbicide. The modular design of the biofilter is very flexible, cheap and does not require a lot of space. The concept of collecting the contaminated liquid in a collection tank and pumping daily about 30 l onto the filter allows to spread out the loading of contaminated liquid onto the biofilter over a long period of time and this will avoid chemical overloading. This procedure will continuously deliver moisture to keep

the micro-organisms active and able to breakdown PPPs. Biofilters can be easily covered to avoid additional rainwater entering the system.
As with the biobed, the biofilters require, from time to time, additional degradable materials to compensate for mineralization of the substrate mixture. The Biofilter can be utilized 6 to 8 years (after which a total refilling of the system with a new substrate mixture is recommended). . General recommendation is to spread the resulting used mixture with a manure spreader on a field at the farm. Such official recommendation to date exists only in very few countries. It is recommended to always check with local authorities which procedure is allowed.

2. Farm conditions

Specific farm conditions will determine how much water and chemical load is generated for the bio purification system and will determine the selection of the optimum system to ensure effectiveness. The number of different crops cultivated and the spray schedule will determine how many times the sprayer must be cleaned to prevent damage and / or residues for the next crop. Beside operator behaviour, the type of sprayer(s) will have a major impact on the potential loads to be treated. Conventional field sprayers have higher amounts of contaminated liquids leftover in their internal system, while air-assisted sprayers (Orchards/Vine) can carry higher contaminations on the outside of the sprayer. Furthermore, the amounts vary by sprayer depending on dimensions of pipes and booms and the design of the spray, tank. The capacity of the rinse water tank and the availability of rinse water determine the quantity of pesticides in and on the sprayer after spraying and cleaning in the field. A sprayer with lowest possible internal residual volumes and a rinse water tank of sufficient size will comply with Best Management Practices (BMPs) and will reduce water and chemical loads needed to be treated by bio purification systems.

3. Chemical and liquid input

One of the important questions that need to be answered before setting up a bio purification system is an accurate estimation regarding likely concentrations of PPPs in the liquid and also what is the likely volume to be treated over a season. Apart from spillages of highly concentrated material before the spraying the main sources of potential water contamination from farms are the handling of internal and external remnants after spraying .
The European Standard EN 12761 sets minimum requirements for crop protection equipment. An important factor is the maximum volume of total residual of a sprayer as defined by ISO 13440. The total residual volume remaining in a sprayer is defined as the volume of spray mixture which cannot be delivered with the intended application rate. This is indicated if the pressure drops by 25% at the manometer. The recommended maximum limits of the European Standard EN 12761-2 for field crop sprayers and EN 12761-3 for air-assisted (high crops such as orchard fruit tree) are shown in table 1 and 2.
As a guide to estimate the amount of diluted spray liquid to be treated the current European standard (EN 12 761) may help to calculate the quantity. If detailed knowledge from the sprayer manufacturer on the total residual volume is available use this information for the calculations (research has shown huge variations of

Table 1: Maximum volumes of total residual for field crop sprayers

Total residual volume in l (EN 12761-2)				
Tank		Boom		
Tank volume	0, 5 %	length m	2l / m	Total litres
800	4	15	30	34
3000	15	21	42	57
4200	21	36	72	93

Table 2: Maximum volumes of total residual for vine/orchard crop sprayers

Total residual volume in l (EN12761-3)		
Tank volume	%	Total litres
400	4%	16
800	3%	24
1500	2%	30

the total residual volumes by different sprayers).
Additional to these volumes, cleaning of the outside of the sprayer also needs to be considered. Currently most farmers are cleaning their sprayers on the farmyard but research has shown that outside deposits are most effectively cleaned in the field and such practice is especially important for air assisted sprayers. Another important requirement specified by the European Standard concerns the capacity of the rinse water tank. The rinse water tank for field sprayers should have at least 10% of the nominal tank volume or at least 10 times the total residual volume.

Farmers should pay attention to these EN Standard as tests have shown that not all sprayers comply. The most economic use of the rinse water is essential, especially if the outside cleaning should be transferred to the field as an effective risk mitigation measure as proposed as the best management practice.
Based on ENTAM sprayer testing results, Debaer *et al.* 2008, showed the significance of diluting the residual volumes in the sprayer by triple rinsing. For field sprayers the chemical load was reduced by a factor of 72 on average between no rinsing (2900 gai) and triple rinsing (40g ai). The rinsing procedure therefore has a huge impact on the chemical load and on what ultimately a bioremediation system needs to “manage”.
Figures 6 / 7 show the differences between sprayers, and the impact of the rinsing procedures for field and orchard sprayers. This impacts the chemical load to be treated by bio purification systems.
For air assisted orchard sprayers the biggest source of contamination is the external chemical load on the sprayer. Depending on the sprayers construction and air assistance system, type of nozzles, and the air flow rate, the external contamination ranges between 0.33% to 0.83% of the applied amount (Balsari, 2006 /ISO-tests).

Example: An apple grower that uses on average 25 kg of active ingredient per hectare each year, the total external contamination of the sprayer can be between 82,5 g. and 207,5 g per hectare.

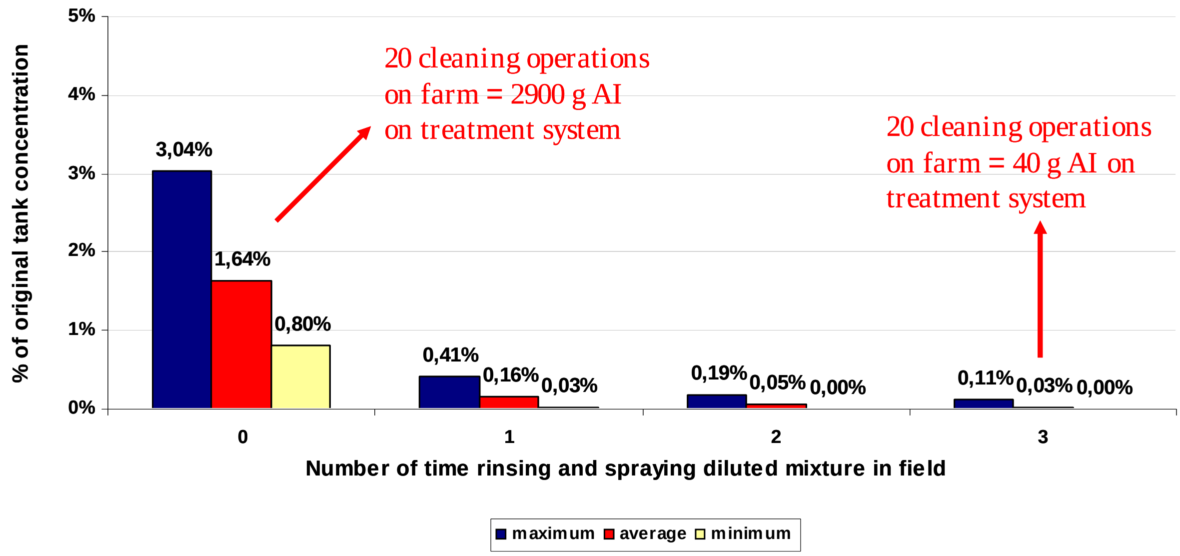

Fig. 6: Chemical loads to be treated by biopurification systems based on ENTAM Field sprayer tests (94 sprayers tested) depending on sprayer designs and rinsing method. In the case of 20 cleaning operation on the farm, and a tank concentration of 1000 g active ingredient in 250 litres /ha, triple rinsing can reduce the chemical load returned to the farmyard by 2860 g. active ingredient for the average field crop sprayer each year (source: Debaer et al, 2008).

For field crop sprayers the external contamination can vary between 0,01% - 0,1% of the applied amount for sprayers without air assistance, but up to 0,47% for air-assisted field crop sprayers (Wehmann, 2006 / ISO tests). For an arable farmer that uses on average only 1,5 kg active ingredient per hectare/year, this is still equal to an external contamination up to 1,5 g per hectare for a conventional field crop sprayer, and up to 7,5 g per hectare for an air-assisted field crop sprayer.
Cleaning the outside of the sprayer in the field reduces the chemical load on bio purification systems considerably, and for orchard crop sprayers this is especially critical. (Note: outside contamination in practices can vary a lot)
Removing the external contamination when it is still wet in the field is much more effective compared to trying to clean off dry deposits back at the farmyard.
Example: At low pressure (4 bar) 97.5% of copper can be removed when the sprayer is cleaned immediately with only 2.55 litres per m² (Debaer *et al*., in preparation) if PPPs deposits are still wet. If the sprayer is cleaned 10 hours after spraying, only 70 % of the copper can be removed, and after 20 hours the cleaning efficiency at low pressure will be further reduced to only 40% with same amount of water. The same cleaning effect after more than 10 hours dry time needs at least 5 times more water at low pressure (12.75 litres per m²). For an average orchard crop sprayer with an estimated surface of 10 m², the difference of cleaning in the field compared to farm is about 100 l of cleaning water. (25.5 litres in the field, 127.5 litres on the farm.
High pressure cleaning systems can further increase external cleaning efficiency, and can reduce the amount of water needed (fig. 8 & 9). Any residue left on the outside of the machinery is subject to weather and rainfall events which at some point (can be over a long period), will remove them and transfer them onto the farmyard.
To limit the amount of chemical loads returned to the farmyard therefore requires essential cleaning procedures executed in the field. This will not only reduce the risk

of water contamination from point sources, it will also reduce the needed capacity for the bio purification systems on farm.

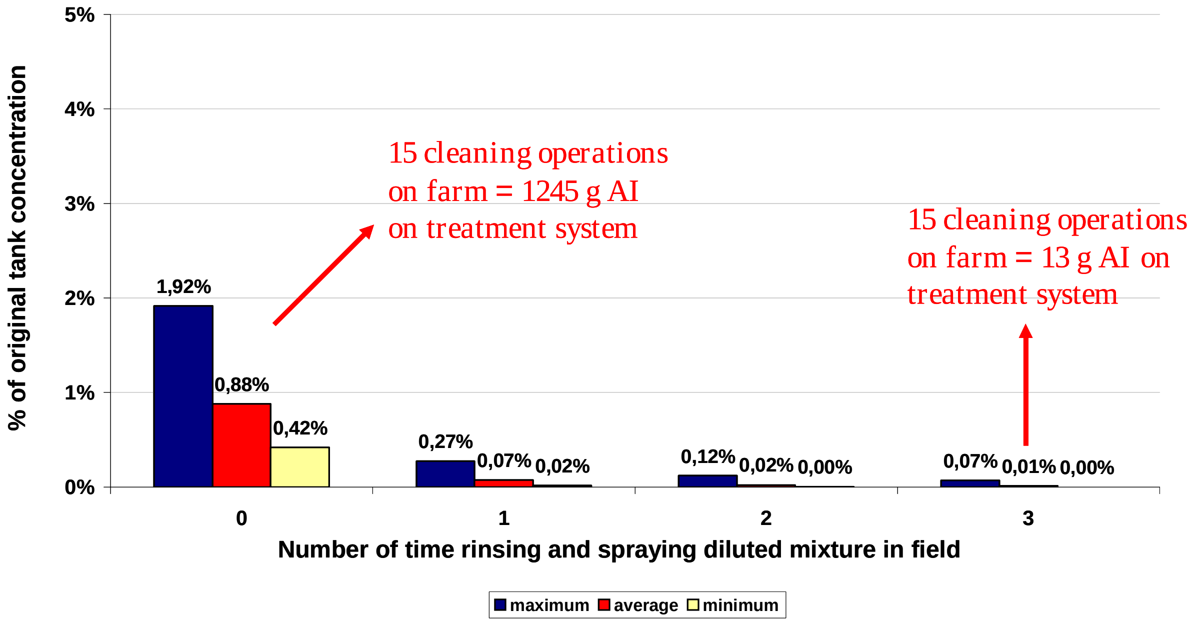

Fig. 7: Chemical loads to be treated by biopurification systems based on ENTAM orchard sprayer tests (23 sprayers tested) depending on sprayer designs and rinsing method. In the case of 15 cleaning operation on the farm, and a tank concentration of 2000 g active ingredient in 250 litres /ha, triple rinsing can reduce the chemical load returned to the farm by 1232 g. active ingredient for the average orchard sprayer each year (source: Debaer et al, 2008).

a. Biopurification summary

The Bio purification systems should be considered as the final steps in the cycle of risk mitigation to prevent water pollution from PPPs.

Fig. 8 & 9: cleaning the outside of an orchard/ tree crop sprayer (source: pcfruit) and a field crop sprayer (LWK-NRW)

The liquid and chemical load managed on the farmyard will determine the setup of the bio purification system. To process low amounts of contaminated liquid at low concentrations eg related with rinsing in the field in combination with only few cleaning operations necessary on farmyard will only require a small biofilter.
High amount of contaminated liquids at a high concentration will inevitably mean a larger bio purification system in combination with a more expensive infrastructure such as special filling and cleaning place. These input characteristics are required if no cleaning is done in the field and a lot of cleaning operations on the farmyard are executed. The most appropriate system in this case is probably a large biobed.
Farmers will have the opportunity to shift risk mitigation more to the field, which means less investments in infrastructure on the farmyard, either for the handling of PPP or the cleaning .

4. Designs of bio purification systems

An integrated filling and cleaning place combines various working processes in a structured way and mitigates the risks of handling PPPs on the farmyard (figure 10). Any spills or unwanted contaminated liquids can be collected and processed.

a) Direct or separate filling and cleaning area

The filling and cleaning area can be directly on top of an installed biobed or in the immediate proximity. Examples of the combined biobed and filling / cleaning place are shown in figures 11 and 12. If the tractor and or sprayer are to be driven onto the biobed then of course they need a structure strong enough to carry the weight of a full sprayer. These systems are best covered with a grass layer to keep a good moisture balance within the system and to support the reduction of collected water (evapotranspiration). Because contaminated liquids are charged directly from the sprayer, a good equal distribution over the surface of the biobed is difficult.
In some cases, only the boom is placed directly above a biobed for collecting contaminated liquids and remnants (figure 13).

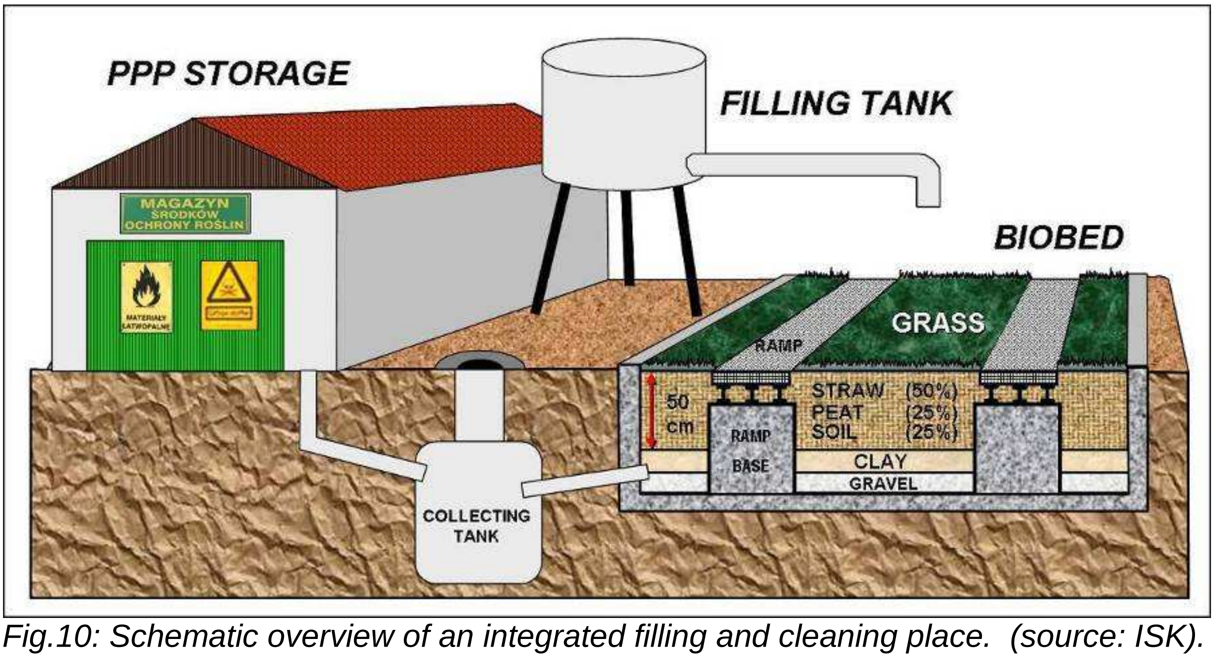

Fig.10: Schematic overview of an integrated filling and cleaning place. (source: ISK).

Similar setups can be used for biofilter installations where contaminated liquids are collected and directly charged onto the biofilter (figure 14). This setup will provide a better distribution of the contaminated liquids over the system. However grass layers are not suitable for biofilters (and would not survive grass herbicide contaminated liquids). The biofilter should be covered from rain, and recirculation of the collected leachate or water is necessary to prevent the top layer from drying out in case of irregular charging. The overview shown in figure 14 allows managing internal cleanings of the tank. Spillages during filling and washings from external cleaning need to be collected and charged to the biofilter separately.

Separate filling and cleaning areas on the farmyard, must be impermeable for PPP contaminated liquids (concrete), and they should be drained directly or indirectly into the bio purification system (figure 15, 16 and 17). Having a separate area will allow all contaminated liquids to be collected first (collection tank) and then charged to the bio purification system. This will provide the possibility to distribute the contaminated liquids equally over the bio purification system as desired over time. However, if the filling and cleaning place is not covered from rain, a separate circuit is needed to exclude rain water from entering the bio purification system.

Research has shown that spills from filling places can drain PPP to surface water over a rather long period. If not all rain can be collected a thorough cleaning of the filling place is necessary (recommendations vary between countries). The bio purification system should always be covered from rain, especially where rainwater can “overload” the system.

Fig. 11: Ramps over a biobed (source: Visavi).

Fig. 12: drive over grid of a biobed

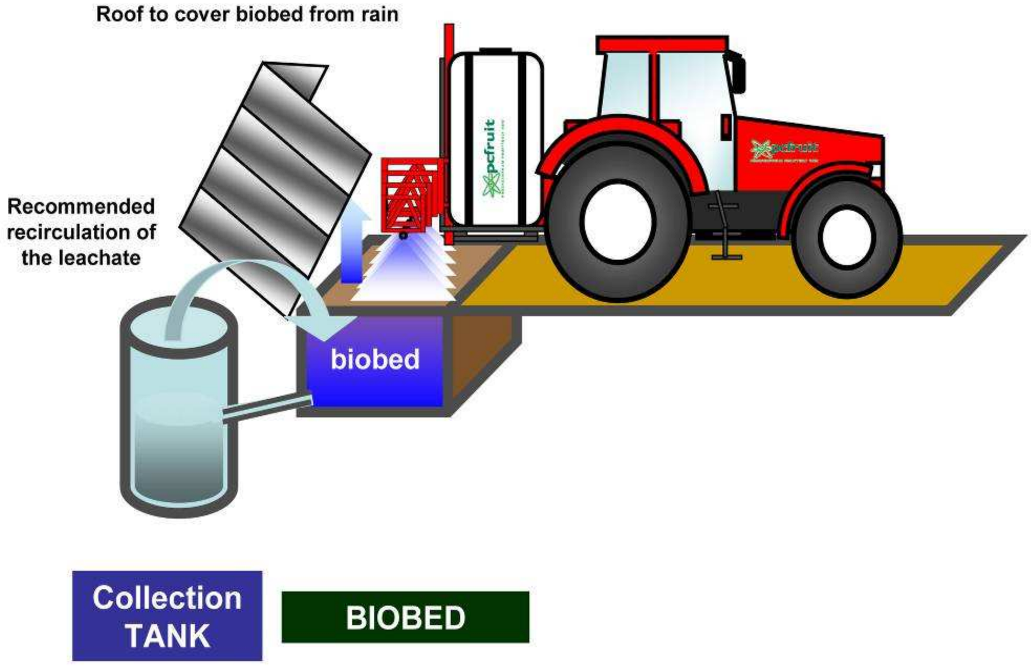

Fig. 13: Schematic example of a biobed used as a direct cleaning area, where the boom is placed directly above the biobed for collecting the sprayed diluted internal remnants (source: pcfruit).

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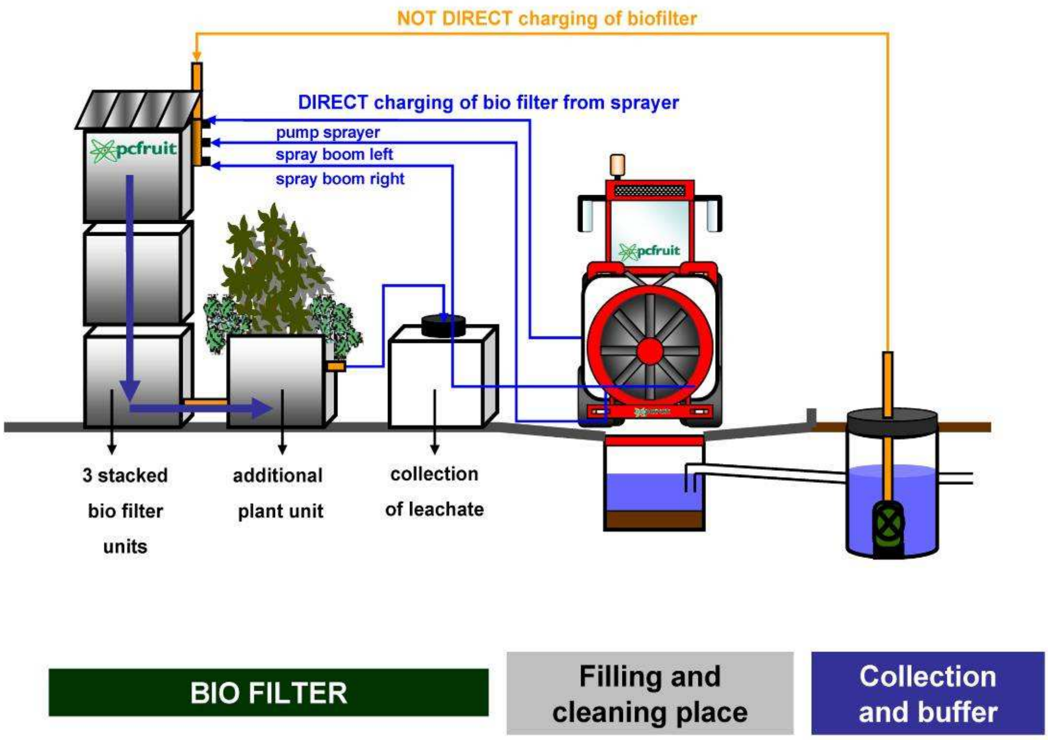

Fig. 14: Schematic overview of direct and indirect charging of a biofilter system. Direct charging only allows the internal diluted spray remnants to be processed. Indirect charging from a separate filling and cleaning area will process all collected contaminated liquids (source: pcfruit).

Fig. 15: Separate concrete filling and cleaning area with filling and cleaning equipment, which drains contaminated liquids to the bio purification system (source: DAAS).

Fig. 16 & 17: Separate concrete filling and cleaning area which drains contaminated liquids to the bio purification system through a concrete path (left) or a drain grid (right) (source: ADAS).

Always make sure that the filling and cleaning area has a border structure (bunded) or a sloping run off surface that keeps contaminated liquids within the area.

b) Buffer or collection tank

A buffer tank is an additional cost, but it is recommended because it allows managing the amount and timing of liquids charged to the bio purification system more equally. The buffer tank size should be equal to the yearly liquid load. Depending on the climate, a bio purification system is active between 200-300 days per year. Low temperatures in winter slow down or stop biological activity of the system. Cleaning operations however, are not equally distributed over the year. For optimal performance, the water and chemical load should be equally distributed over the whole active period of the system to ensure continuous biological activity.

Example: if the yearly liquid load is 5000 l., and the active period of the system (days above 15-20℃) is 200 days, this means that ideally 25 l. a day should be charged onto the system. In connection with a buffer tank the system works optimally, and the dimensions of the system can be limited. For charging the bio purification system with low volumes each day, a low flow rate pump in combination with an electronic timer (not continuous), or a dosing pump (continuous) can be used (figures 18/19).
In cases where remaining spray solution cannot be diluted and sprayed out in the field a buffer tank, which collects all contaminated liquids, allows that the dilution steps are done in the buffer tank by adding fresh water, because diluted liquids may degrade better.

c) Open versus closed systems

In figure 20 a schematic presentation is given of closed and open biobed systems.
Closed systems are more like a batch system, where excess water or moisture can only leave the system through evaporation. 1m³ of substrate will evaporate on average between 400-500 litres of water each year, depending on the climate. This means that a closed system needs 2m³ of substrate to treat 1000 litres of contaminated liquid. (Data represent situation of Belgium, with an average temperature around 11℃ and an average rain fall of 800 mm each year) We recommend checking with your local advisor how much in your area would be evaporated during a year.
Generally the closed systems have the risk that in case of lower evaporation and/ or more contaminated liquid to be treated, the systems will saturate or overflow. Saturation will seriously affect sorption and degradation of PPP within the active substrate resulting in leaching (Fogg *et al*, 2004). Saturation can be prevented by covering the system from rain and spreading the liquid load in time.
The main advantage of closed systems is that there is no remaining leachate but this is only true if the evaporation is higher than the amount of contaminated liquids being charged onto the system.


Fig. 18 & 19: example of a 4000 l. PE buffer tank above ground and a 5000 l. concrete buffer tank beneath the filling and cleaning place with separation valve for rain water (source: pcfruit).

An open system is more like a cross flow system, where a part of the water is evaporated, and remaining water is collected as leachate. In an open system 1m³ active substrate mixture can process 1,5 m³ contaminated liquid, of which 0,5 m³ water evaporates and 1m³ leachate can remain. This example shows that open systems can treat more contaminated liquids with the same amount of active substrate mixture, but the remaining leachate must be collected in a separate tank. This leachate can be re-used as liquid for nonselective herbicide applications in the field, or being recycled in the bio purification system. The use of vegetation provides additional purification and evapotranspiration of the leachate. An optimal moisture balance of 95% within the system when continuously charged showed best results.

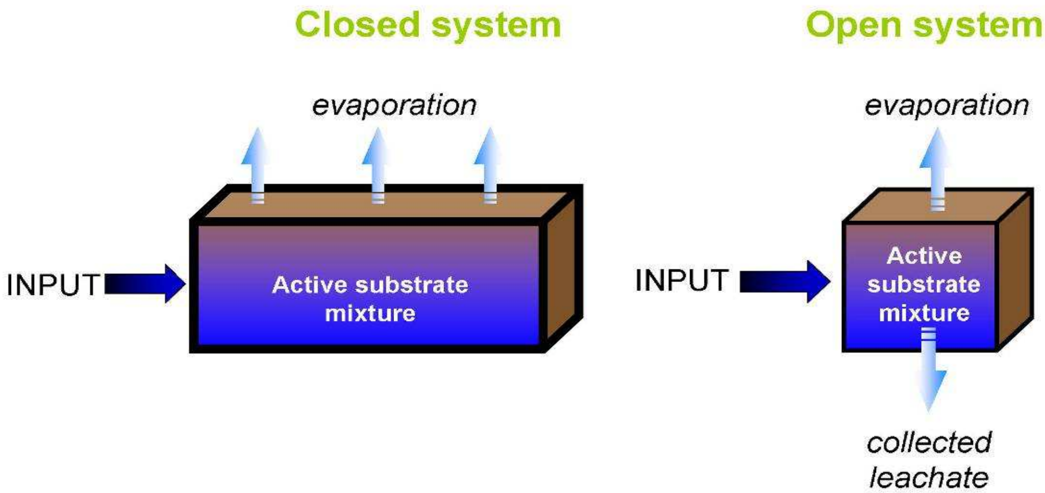

Fig. 20: schematic representation of a closed and open system.

d) Equipment for charging a bio purification system

Contaminated liquid should be evenly distributed on the surface of a bio purification system. Different technical solutions are possible. In figure 21, a metal plate splashes the contaminated liquid over the surface of the active substrate mixture of a biofilter. A perforated circular hose (figure 22) on top of the substrate of a biofilter is a more controlled way of distributing contaminated liquids. Also spray nozzles can be used for an optimal distribution (figure 23). Apart from spray nozzles, which can be used in small and large systems, perforated pipes (figure 24) or drip irrigation systems (Basford *et al.,* 2004) are also an easy way of distributing contaminated liquids over a large surface. Regular charging of bioremediation systems require a tank where contaminated liquid is collected.

e) Lining of systems

Bio purification systems must be lined by an impermeable material. Usually the sides of a biobed system are made out of concrete, but also plastics such as EPDM (figure 25) or PE (figure 26) are a possibility. Biofilter systems are traditionally constructed out of 1m³ containers or IBCs of PE. The lifespan of plastics is however much shorter than that of concrete. Exposed to light, PE containers will last for about 10 years.

Fig. 21 & 22: Distributing the contaminated liquid over the surface by means of a metal plate (left, source CRAw) or a circular perforated hose (right, source pcfruit).

Fig. 23 & 24: Distributing the contaminated liquid over the surface by means of spraying nozzles (left, source POVLT) or a circular perforated pipes (right, source Bayer CropScience).

Fig. 25 & 26: As an alternative for concrete, biobed can also be lined with plastics such as EPDM (left, source ADAS) and PE containers (right, source Mybatec).

f) Cover from rain and / or separate circuit for rain and non contaminated water

Bio purification systems should be covered from rain when using a separate filling and cleaning area. Only if the bio purification system uses additional vegetation, it should be open or covered by transparent materials to ensure sufficient light. .

Examples of covered bio purification systems are given in figures 3, 4, 24, 26, 32, 33, 37. Covered bio purification systems will exclude clean rain water, and avoid saturation and overloading of the biobed.
All none contaminated water of the filling and cleaning area should not enter the bio purification system for the same reasons explained above.
Research showed that spills from concrete filling places can be washed off by rain over a longer period. Therefore spills need to be cleaned carefully after the spray operation has stopped otherwise the rainwater from the filling place should be collected in the biopurification system.

g) Drainage of the system

Open systems, like biofilters, always need a drainage system at the bottom of each bio purification unit, to lead the leachate to the next unit or the leachate collection tank. The most practical way is to use a drain pipe, shown in figure 27. Using a drain pipe will not only drain the liquid effectively, but also guarantees that no particles from the active substrate mixture can cause blockages to the hydraulic system or valves. .
Drain pipes can also be used for biobeds. As shown in figure 10, using gravel in combination with clay, is also a possibility, but using clay will slow down drainage considerably, and if the clay drys out , cracks may be formed.

Fig 27: drain pipe at bottom of biofilter unit.

h) Use of vegetation

The use of vegetation can have a lot of advantages. The grass layer on top of directly charged biobeds keeps a good moisture balance by evaporating excess water, and prevents the top layer from drying out (figures 2, 10, 11, 28). Also, the root system can optimize soil conditions for microorganisms, which are responsible for the degradation of PPPs. Contaminated liquids directly charged onto a biobed may cause phytotoxicity of the grass cover if not sufficiently diluted. Biofilters can utilise vegetation in attached units when the concentration of PPPs (especially herbicides) is low enough to guarantee the survival of the specific vegetation (figure 29). Research showed that grasses (*Carex* spp.) are more resistant to herbicides, but bushes and trees (*Salix* spp.) have higher evaporation capacities (Debaer *et al.*, 2007). *Carex spp*. increased the evaporation of the system by more than 500 litres per planted m² per year while *Salix spp.* increased the evaporation by about 1000 or more litres per year. When using enough plant units to evaporate excess water, open biofilter systems can become zero leachate systems


Fig. 28 & 29: Grass layer on top of directly charged biobed (left, source Visavi) and Carex spp. *in the final unit of a modified biofilter (right, source pcfruit)*

To avoid possibilities of weed invasion into the field select suitable non invasive plants. The plants selected should be non toxic and should not deliver any edible fruit or other edible parts.

If no herbicides are being used on the biopurification system select a dicot shrub to help evaporate excess water. For situations where herbicides are used with grass and dicot activity, above mentioned Carex and Salix species are recommended.

i) Examples

I. lined biobed systems

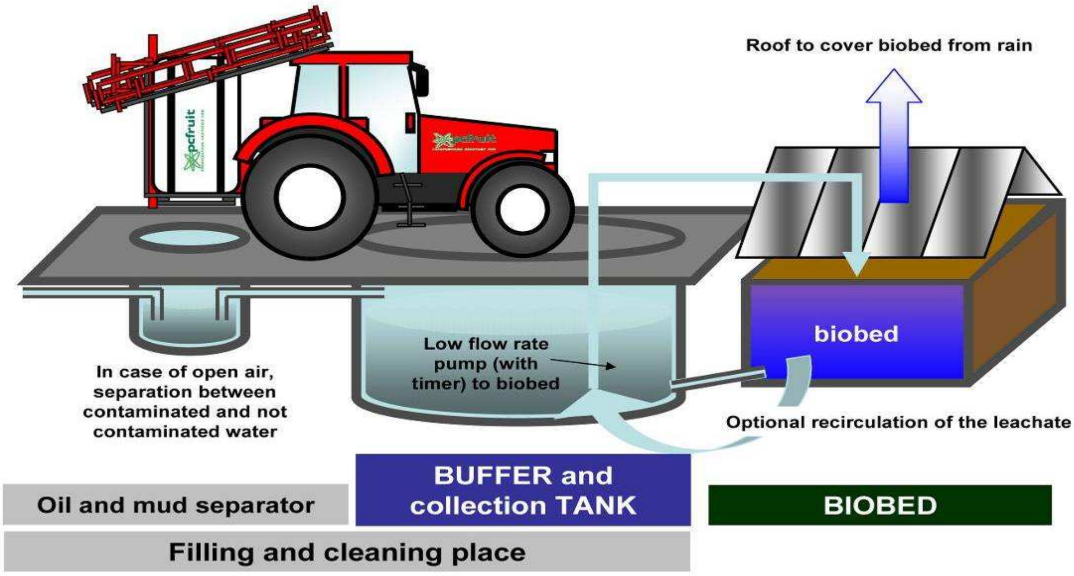

Fig. 30: Schematic example of how a modern lined biobed is constructed and equipped. Contaminated liquids are separated from rain but also from mud. The buffer and collection tank allow the liquid and chemical load from the separate filling and cleaning area to be distributed over time. Possible saturation can be avoided by covering the biobed and protecting from rain, and draining and re-circulating possible leachate. (source pcfruit)

II. Examples of biofilter systems

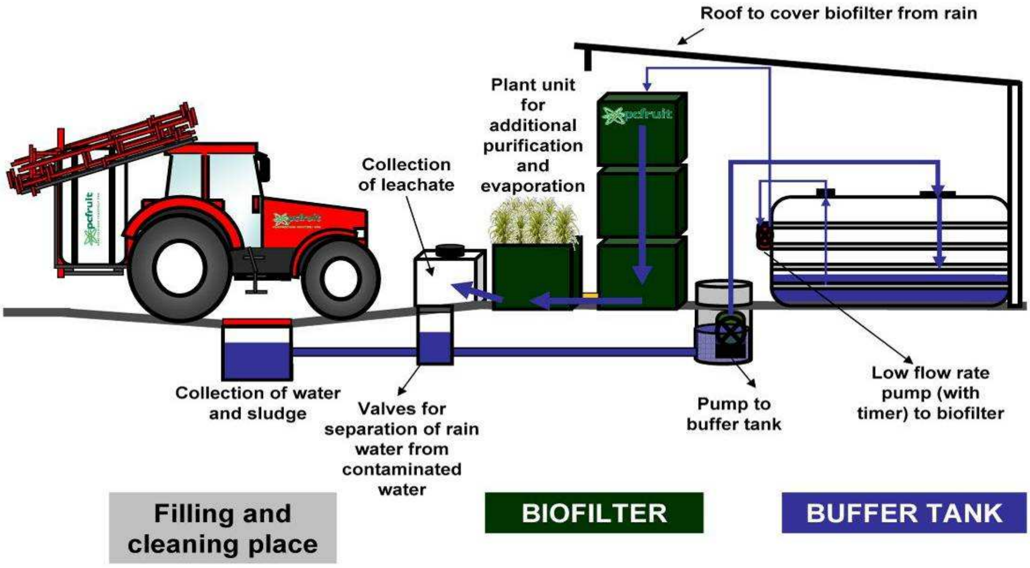

Fig. 31: Filling and cleaning area (in open air) equipped with a covered modified biofilter of 3 + 1 units (source pcfruit). Separation of clean rain and wash water is controlled with a valve system. Contaminated liquids are pumped in a buffer tank of 4000 litres. From the buffer tank 25 litres a day is charged on top of the biofilter. This system has been charged with 6300 litres in 2007, 4000 litres leachate was collected, 2300 litres water was evaporated (Debaer et al.,2007).

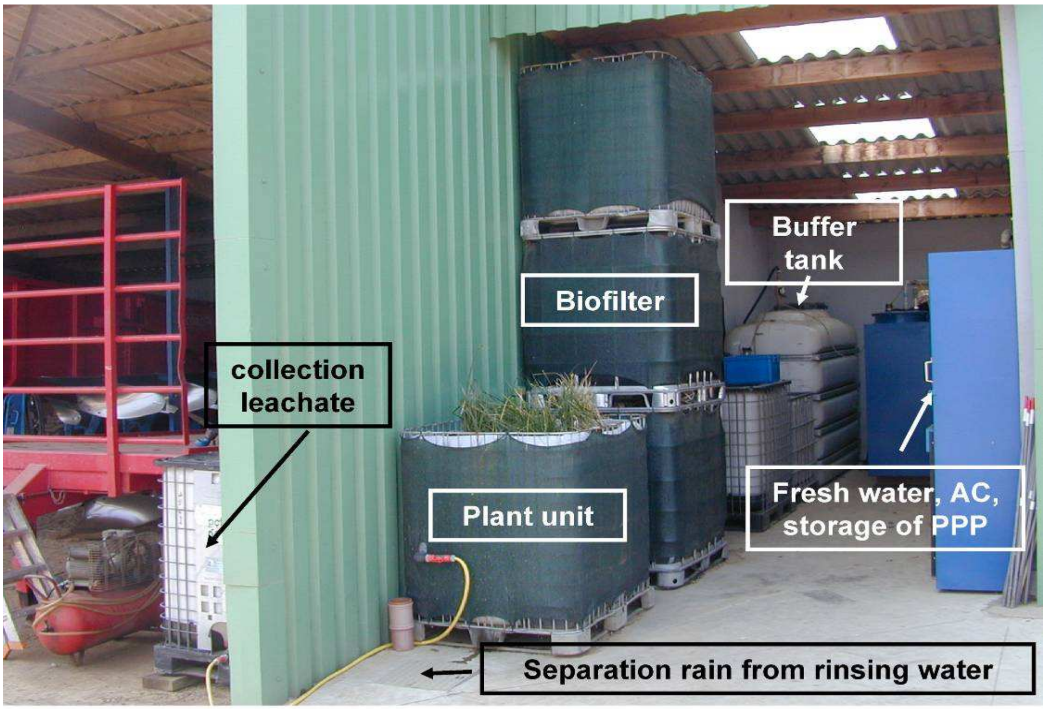

Fig. 32: Integrated filling and cleaning area equipped with a modified biofilter of 3 + 1 units, also represented by figure 31 (source pcfruit). The overflow drainage of the plant unit is situated just beneath the root zone of the specific plants. All remaining leachate is collected.

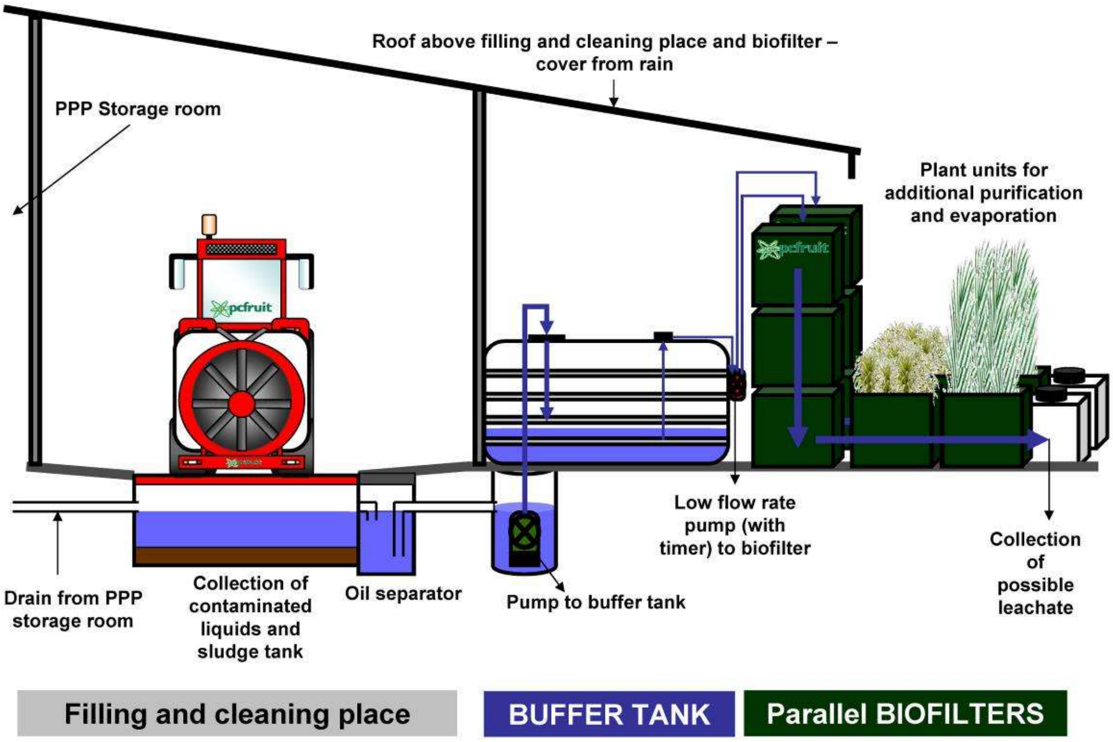

Fig. 33: Integrated filling and cleaning area equipped with a 2 parallel modified biofilter of each 3 + 2 units (source pcfruit). Both the filling and cleaning area and the biofilters (except the plant units) are covered by a roof to keep clean rain water out of the system. All remaining leachate is collected.

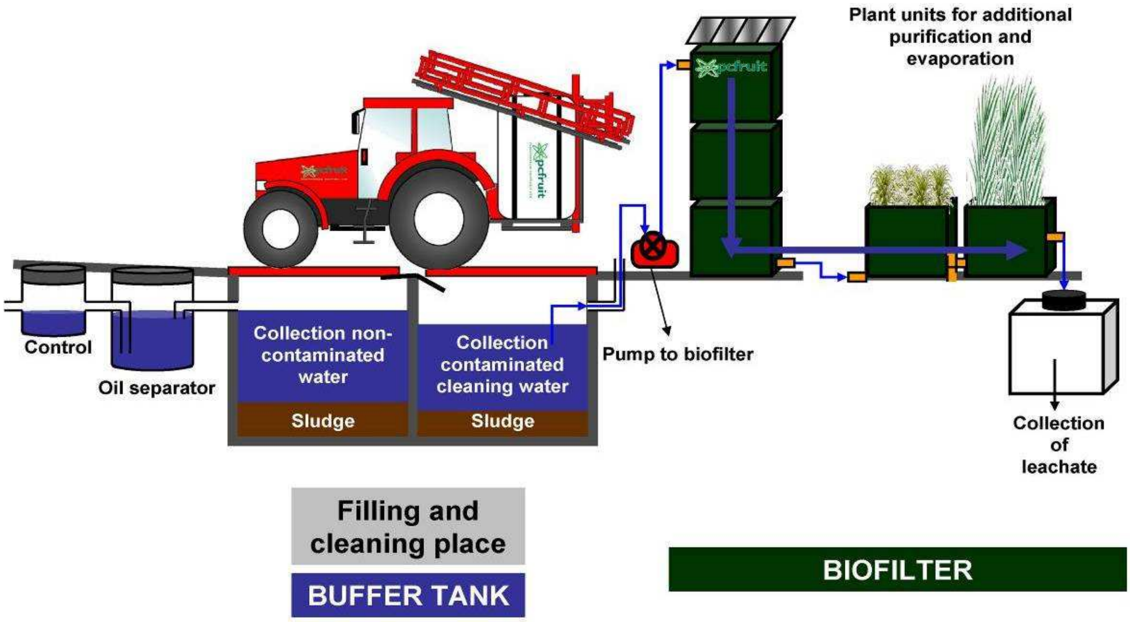

Fig. 34: Filling and cleaning area equipped with a modified biofilter of 3 + 2 units (source pcfruit). Rain and washing water is separated into 2 buffer tanks below the filling and cleaning area. The contaminated liquids are pumped on top of the covered biofilter with a timer controlled pump. All remaining leachate is collected.

Fig. 35 and 36: To provide an optimal moist balance in 2 top units of the modified biofilter, a saturated zone is kept at the bottom of the unit to allow water to rise up through capillary force. This can be achieved by connecting the outlet of the unit to a pipe that is bend upwards and has an air duct leading to the top of the unit. The height of the saturated zone is determined by the height the outflow pipe is bend upwards. Different heights can be made (left) to choose from, or on saturated zone of 300 litres can be sufficient (right). After bending the outlet pipe, lead the end to the top of the next unit and distribute the leachate as shown in pictures 21-24. Other valves on the units in the pictures are used to sample the system, or to drain the system for winter storage and prevent the valves from freezing. (Source: pcfruit).

5. Dimensioning bio purification systems

The amount of filter substrate needed to treat a certain volume of contaminated liquid for open or closed systems has already been discussed (chapter 4, section IV).
For closed systems capacity considerations are based on the possible evaporation to avoid saturation of the substrate mixture. Important for open systems is the filter efficiency (Pussemier *et al.*, 2004; Pigeon *et al.*, 2005; Debaer *et al.*, in preparation). There is a general misconception that biobeds (closed systems) are capable of treating more contaminated liquids than biofilters (open systems). This may be related to the fact that biobeds are dimensioned as big systems, using more active substrate volumes than the smaller biofilters. In fact the same volume of active substrate mixture in open systems can treat larger volumes of contaminated liquids <u>if the remaining leachate is collected and recycled</u>. Open systems using vegetation however can, with proper dimensioning, become zero output systems with no remaining leachate.
It is clear that under all conditions the chemical and liquid input should be minimised as far as possible. At the output side of the system, liquid and solid waste should be minimised by proper dimensioning according to the needs.
The main principle of purification is the breakdown of the PPPs , not only a reduction of the concentration. Therefore, planning of biopurification systems need to balance the inputs and outputs. This can be best explained with one example for a closed

system (biobed), and an open system (biofilter) as well as for a zero output open system (modified biofilter), which is shown in figure 37.

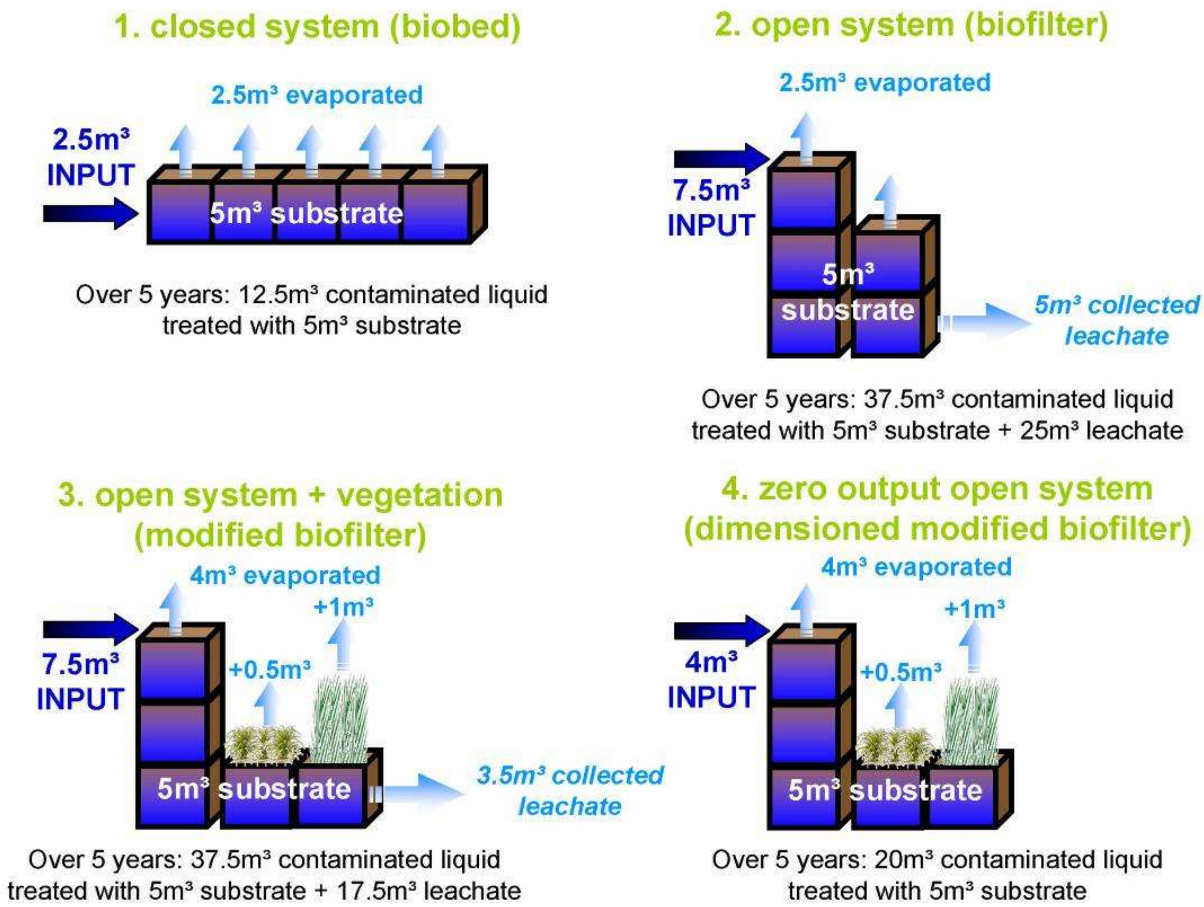

Fig. 37: Examples for considering the dimensions of a bio purification system
1 represents a typical biobed system. Where large volumes of active substrates are needed
2 is a typical biofilter system with a large remaining volume of leachate which needs to be re-used in the field or recycled.
3 example of the contribution of vegetation to increase the evaporation of excess water, which is only possible in open cross flow systems.(2,5+0,5+1=4m³) By experience in this specific example, the purification of the first 3 units will not be sufficient for the plants to survive in unit 4 and 5 if undiluted concentrated spray remnants are charged to the system (no cleaning in the field).
4 indicates that a well dimensioned open system using plants can give zero output , with the highest capacity and efficiency for treating contaminated liquids. However, for high volumes of contaminated liquids, the physical design is more demanding. (Source pcfruit).

6. Active substrate mixture (different substrates and function)

Originally the typical substrate mixture used in bio purification systems consisted of 50% straw, 25% peat and 25% topsoil. Various studies have investigated the ratios of the mixture and the use of alternative substrates for best PPP degradation.

a) Topsoil – source of micro-organisms

Topsoil taken from the fields where application of the PPPs has previously been undertaken contains the essential micro-organisms to degrade PPPs when incorporated in the substrate mixture. Micro-organisms in the topsoil can be fungi or bacteria, and they use PPPs as a source of carbon for nutrition. It is important to use topsoil from the farm, because the micro-organisms are adapted to the PPPs used in the field. Topsoil is the only component in the active substrate mixture that cannot be replaced by an alternative. The ratio or amount of topsoil however can
be reduced without losing degradation activity. This can be an advantage in case spreading of used biomatrix is not possible and needs to be incinerated. (This is the case in situations where no recommendation / regulations for biopurification systems may exist)

b) Straw

Straw acts as an additional food source for micro-organisms. Straw is a source of lignin, which is essential for micro-organisms that produce lignin degrading enzymes which can degrade a broad spectrum of PPPs. Straw is also a Nitrogen-source, resulting in a overall good C/N ratio for degrading bacteria. Active substrate mixtures mineralise straw rapidly resulting in a 10% loss of substrate each year. Straw therefore needs to be added after each season to the system.

c) Coconut peal

Coconut peal can (partially) be a Carbon - source as a substitute for straw, combining good water holding properties with good aeration. Active substrate mixtures with coconut bark or peal mineralise much slower than those with straw, reducing the need of refilling and mixing the substrate mixture each year. Replacing straw by coconut peal doesn’t affect the degradation efficiency.

d) Peat

Peat is a substrate which provides numerous sites for pesticide sorption. It helps to maintain aerobic conditions combined with the essential moisture due to its water holding capacity. Peat is however a non-sustainable raw material therefore not recommended.

e) Potting soil

Potting soil has the same functions and characteristics as peat, and can replace it in the active substrate mixture. Potting soil often contains white and black peat, but in some potting soils the peat is often partially or completely replaced by coconut materials.

f) Cow manure

Manure is an additional substrate to increase the N source by adding nitrate. Research (Genot et al, 2002) has shown that addition of manure can increase the degradation of PPPs. This is mainly the case for bacterial degradation. Research where degradation was mainly performed by fungii showed that low N content kept microorganisms hungry to degrade PPPs. (Castillo et al 2008). As a rule of thumb a C/N ratio in the matrix of 10 to 20 should be targeted.

7. Mixing of substrates

Originally the substrate mixture used in biobed systems consisted of 50% straw, 25% peat and 25% topsoil. However, present research has proved that

- The topsoil fraction is best suited to inoculate the system, but can then be reduced to less than 5% without any loss in degradation capacity (Sniegowski *et al in* preparation). The reduction in top soil can even increase the retention of PPPs in the system and therefore biodegradation (De Wilde *et al.*, in preparation).
- Alternatives such as coconut peal and potting soil mixed in different ratios within the active substrate mixture doesn't affect retention (De Wilde *et al.*, in preparation).
- Adding 5 to 10 % of cow manure can increase retention and degradation of PPPs within the active substrate mixture (Genot *et al.*, 2002; De Wilde *et al.*, in preparation).

Figure 38 shows different possibilities of active substrate mixtures according to present research. Replacing straw in the top unit of a modified biofilter by coconut peal, buffers the system. In the next units the topsoil fraction is reduced to 5-10%, and the potting soil is increased to 40%, giving a better retention potential in the unit and increasing biodegradation. With addition of 5-10% cow manure one could reduce the potting soil to 30-35%. Plant units are best filled with a drain layer of coconut bark at the bottom (10%) and 80-90% potting soil on top, mixed with 0 -10% of cow manure.

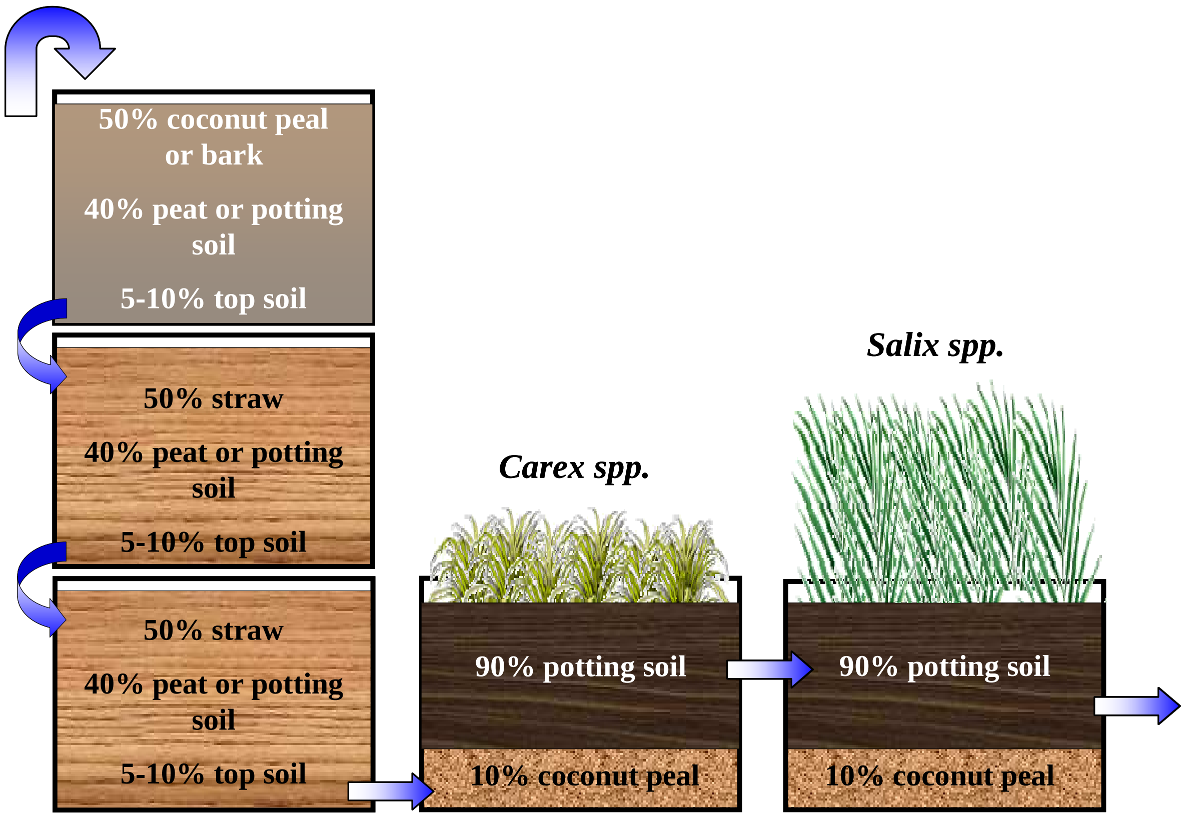

Fig. 38: Example of active substrate mixtures in a modified bio filter (source pcfruit).

Ratios of substrates are always expressed by volume. For making homogenous mixtures, the maximum size of all the particles in the mixture is best kept at 2-4 cm. (f.e straw length should be max 4 cm). Thorough mixture of the filter substrates can be obtained by using an ordinary concrete mixer.

a. Filling the bio purification system with the mixed substrates

Filling the lined system with the active substrate mixture is a balanced process. If the mixture is well compressed, the retention will be high due to slow penetration and long contact time between the contaminated liquids and the mixture. However, a well compressed mixture doesn't have very good aeration needed for aerobic degradation of PPPs. On the other hand, if the active substrate mixture isn't compressed at all, retention will be low, especially when the contaminated liquids aren't distributed very well, and leaching can occur rapidly. Mixtures containing a low amount of soil, and thus a higher amount of peat or potting soil will have a better aeration, even if the mixture is compressed.

b. Maintenance of active matrix

The longer a system is in use, the total content of carbon and microbiological activity will decrease due to mineralisation of the active substrate mixture. Mineralisation of the active substrate depends on the composition and the particle size of substrate components. A mixture which contains 50% of shopped straw will mineralise and reduce the amount of active substrate by approximately 10 cm each year. To compensate this loss, fresh material can be added and mixed with the remaining substrates each year or every second year. Always maintain a minimum filter depth of more than 60 cm. After some years, the mixture needs to be replaced completely because it is exhausted. Torstensson (2000) stated that in the south of Sweden the active substrate mixture should be replaced after 5-6 years.

8. Sorption and biodegradation processes

International research has shown that under different and often non-optimal operating conditions 93% of the PPPs loaded on the system were biodegraded, while on average 4% was found in the leachate, and 3% was retained within the active substrate mixture. Under optimal conditions more than 99% of PPP were retained and biodegraded within bio purification systems, with the exception of a few specific "mobile" PPPs.

a. Principle

The control and optimization of bio purification processes is a complex system of many factors. These factors include the existence of microbial populations capable of degrading the pollutants and being available to them. Environmental factors like type of soil, temperature, pH, the presence of oxygen or other electron acceptors, and nutrients also influence the efficiency of degradation (Vidali, 2001). Another major constraint is the accessibility of the pesticides for micro-organisms (bioavailability - Thompson, 2001). The biodegradation of an organic compound is almost exclusively situated where pollutants are dissolved in the soil moisture that surrounds the micro-organisms. In other words, it is within a thin water layer on the surface of substrate particles where the micro-organisms are situated. Therefore increasing the specific surfaces of a substrate, without losing bioavailability due to micro pores (clay), will support better biodegradation by micro-organisms. (Fig.39)

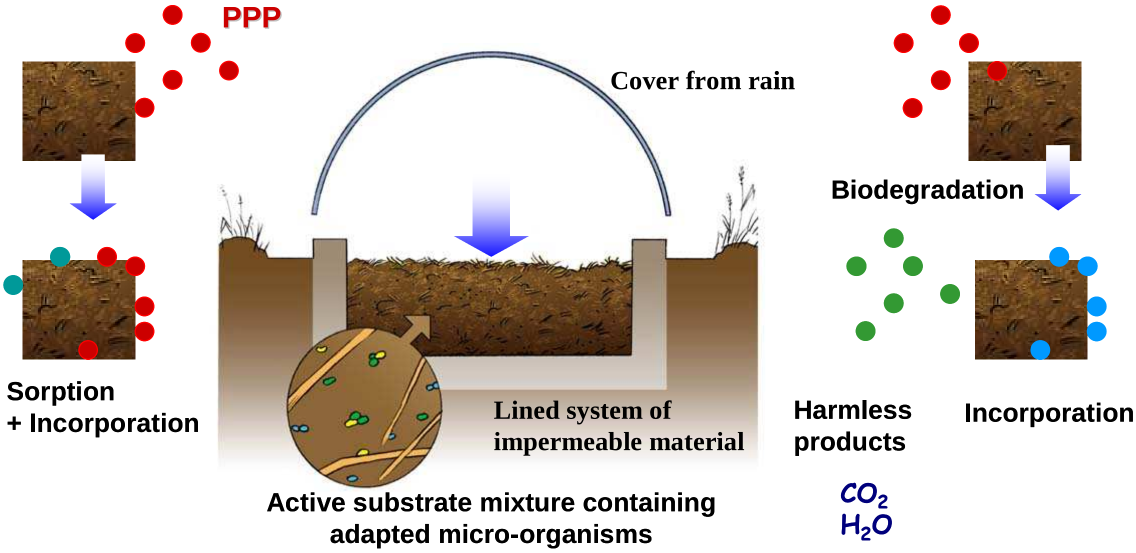

Fig. 39: The 2 chemical processes involved in bio purification of PPPs. On the left sorption and incorporation are illustrated. On the right biodegradation of PPPs is illustrated, which can take place after sorption of PPP on the substrate, and which degrades PPPs. (source: Bayer CropScience and KULeuven).

b. Important factors influencing sorption and biodegradation

The influence of different factors on the degradation of pesticides has been studied.

- High PPP concentrations can limit biodegradation (Fogg *et al.*, 2003). Therefore as mentioned before, it is strongly recommended to clean the sprayer in the field for optimal efficiency of the bio purification system and treat only remaining diluted spray solutions.
- Degradation can be inhibited in topsoil when applying mixtures of PPPs, but it is not inhibited within the active substrate mixture. This suggests that bio purification systems can degrade a wide range of PPP mixtures (Fogg *et al.*, 2003).
- The moisture content in a bio purification system is essential for the bio purification processes (optimal 95%). However, saturation (100%) can lead to leaching of PPP directly correlated with the liquid load on the system (Fogg *et al.*, 2004). To avoid leaching of mobile PPP, the depth of the bio purification system can be increased or substrate saturation needs to be avoided
- Repeated use of certain PPP over several seasons can result in an enhanced degradation due to adaptation of the micro-organisms (*Fournier et al.*, 2004)

9. Leachate

Leachate should be collected at all times. NEVER DRAIN LEACHATE IN OR NEAR SURFACE WATER. Depending on legal and farm specific situations, the following destinations and actions are possible:

- Re-circulation of leachate into the bio purification system. This will increase evaporation.
- Re-use of leachate for non selective herbicide applications in the field.
- Spreading leachate in the field, taking care of buffer restrictions for surface water.
- Evaporate the leachate by using vegetation in a last purification phase.
- Dispose of the leachate by a legal waste processing company if no other legal options exist.

10. Substrate mixture after its use

The substrate mixture will have to be completely replaced after several years of service (6 to 8 years). Depending on legal and farm specific situations, the following destinations and actions are possible:

- Spread the used substrate with a manure spreader on a field to further degrade any PPP remains in the field

- Compost the substrate mixture on a covered impermeable structure and avoid any leaching to water for one or two years. Mixing the composting substrates twice a year and keeping it moist will further degrade any left over PPPs . After 1 to 2 years composted substrates can be safely spread onto the field.

- Dispose of the substrate mixture through incineration by a legal waste processing company if no other legal options exist.

11. Considerations to decide on the suitable bio purification system

The following considerations are based on research mainly done in Belgium. Modifications may be necessary depending on climatic conditions and on local recommendations / regulations. Please consider the following questions to help in adapting the system to your specific situation and needs.

a. The bio purification system will have to process high volumes and highly concentrated liquids (no cleaning in the field).

Each year more than 10.000 litres of contaminated liquids are produced on your farm, and there are few or no possibilities to rinse and clean the sprayer in the field. In such a situation your best option is to use a **lined biobed system** that is big enough to handle the contaminated liquid / water volumes.

- For each 1000 litres of contaminated liquid 2m³ active substrate is needed.
- Make sure that the input volume is spread over time during the year and is well distributed over the surface of the active substrate.
- Prevent rain and non contaminated water from entering the system. This will avoid saturation and leaching of the active substrate

b. The contaminated liquids will be charged directly onto the bio purification system.

There is no possibility to temporally store contaminated liquids in a buffer tank, and the liquid and chemical input is not equally distributed over the year. The best option is to use a **lined biobed system whose dimensions can easily handle** the liquid input.

- For each 1000 litres of liquid input 2m³ active substrate is needed.
- Make sure that the input is well distributed over the surface of the active matrix. Avoid preferential flow near the side of the system.
- Charging the system will be very irregular. Recirculation is probably needed to prevent the top layer from drying out and consequently will stop evaporation and bio purification processes. With higher liquid loads leaching of PPP through the active substrate can also occur. Recirculation will provide an adequate purification of the leachate.
- Prevent rain and non-contaminated water from entering the system. This will avoid saturation and leaching of PPP through the active matrix.

c. After use the active substrate can not be disposed legally into the field

Biobed systems have higher amounts of active substrate. If the active substrate can not be disposed of legally in the field, processing by incineration could be a legal option but will cost a lot of money. Therefore, in this case a **lined biofilter system** would be preferable to a biobed system.

d. The bio purification system will have to process indirectly charged low volumes or diluted contaminated liquids (cleaning in the field)

Each year less than 10.000 litres of contaminated liquids are produced on your farm, and / or the sprayer is rinsed and cleaned in the field. Possible leachate can be re-used or disposed of legally onto the field. The best option is to use a **lined biofilter system** that is well dimensioned to manage the liquid input.

- For each 1500 litres of liquid input 1m³ active substrate is needed. This will result in 1000 litres leachate per year when no additional plant units are being used. Collect and re-use leachate in the field if possible.
- Prevent rain and non contaminated water from entering the system. This will avoid saturation and leaching of the active matrix. If using plant units ensure the plants have enough light.
- Make sure that the input is spread over time and volumes are equally distributed on the surface of the active substrate. Collect contaminated liquids and any leachate in a buffer tank. Use a pump with low flow rate (dosing pump) or a regular pump with an electronic timer to charge the system daily with small amounts (about 30 l)). Example: 5000 litres each year over a period of 200 days = 25 litres per day.
- Preferably use black containers or IBCs for making a biofilter system. This will provide more heat and stimulate activity of the micro-organisms .
- If the charging of the biofilter is irregular (time), it is recommended that a saturated zone is maintained in the lower half of the biofilter unit to constantly provide the active matrix with enough moisture.
- Use plants with biofilter installations to reduce leachate and make the system a zero output system where the recycling of leachate is not necessary.

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Contributions and comments from various TOPPS partners completed this document.

Local partners performed the translation and the necessary adoptions of this document to their situation and regulatory framework.

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