Maria del Pilar Castillo
Department of Microbiology
Swedish University of Agricultural Sciences
Box 7025
750 07 Uppsala

Final report
Mitigation of pesticide leaching in biobeds

Purpose of the project
To study the potential pesticide leaching from biobeds and design of a system for its mitigation.

Background
An important point source of contamination by pesticides is the filling or cleaning of the spraying equipments. However, the use of simple units as the biobeds has minimized the risks of pollution from this point source.

Defining the concept of biobed

A biobed is a simple and cheap construction on farms intended to collect and degrade spills of pesticides (Torstensson & Castillo 1997, Torstensson 2000). Biobeds are facilities composed of: a) a biomixture or biomix (mixture of straw, mineral topsoil and peat); b) a grass layer that covers the biobed, and c) a clay layer at the bottom of the biobed. A biobed is also equipped with a ramp making it possible to drive the tractor and sprayer over the bed. It is important to strengthen that the definition of biobed implies these three parts together, biomix, grass and clay layer. And this is because in some literature the biobed is a synonym of just the biomix and this is not the case.

What are the functions of the three parts of a biobed? A good functioning biobed implies that these three parts of the system should be working properly:

a) the purpose of the clay layer is to limit the flow of water downwards. In order to achieve this, the clay should be enough wet to swell and form a homogenous and compact structure. A dry clay layer will enhance the formation of cracks and the risk for preferential flow.
b) the purpose of the biomix is to retain and degrade the pesticides. To achieve this, the biomix should have a good absorption capacity and a high microbial activity. Both capacities are enhance by the homogeneity of the mixture and by the particle size. It is known from other solid substrate fermentation systems (SSF) that good mixing and smaller particle size increases the specific area and hence enhances the sorption and microbial activities.
c) the purpose of the grass layer is to promote an upwards water transport and to serve as a pedagogic tool to recognize the spill areas.

To clear up also some of the terms commonly used we can define what is lined and unlined biobeds.

a) an unlined biobed (Fig. 1) is such that there is no impermeable synthetic layer at the bottom of the biobed. To this group belongs the original Swedish design of the biobed (also called “normal” design). This system consists of a hole in the ground that is covered by the clay layer at the bottom followed by the biomix and covered with a grass layer at the surface. In many cases, especially in the south of Sweden, the soils are usually clay soils, which mean that a natural clay layer is used at the bottom of the biobed (Fig 1a). In other cases an “artificial” added clay layer is to be used (Fig. 1b). No collection of leakage water is possible in this system.

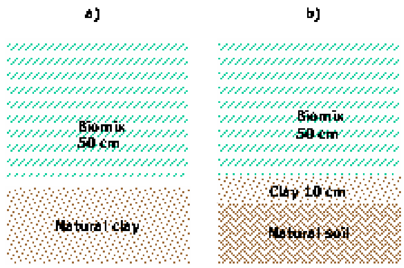

Fig. 1 Unlined biobeds with a a) natural clay layer and b) an artificial added clay layer

b) A lined biobed is such that uses an impermeable layer (plastic, concrete, etc) covering the entire hole in the ground. The clay layer, biomix and grass are located above the impermeable layer. Usually another layer (gravel, macadam or sand) for draining purposes is located below the clay. This system is close and allows the collection of the leakage water in special wells that are built at the side of the biobed.

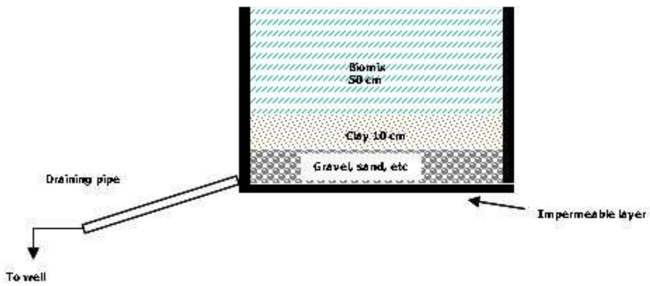

Fig. 2 Lined biobed showing the impermeable layer that closes the system from the outer environment and allows collection of drainage water.

Leaching of pesticides from biobeds in Danish and English studies

According to studies done in Denmark (Henriksen et al, 2003), 8 pesticides from 21 tested were detected in the leachate of a biobed. The biobed had a profile consisting of 50 cm biomix, a 10-cm layer of clay and a 10-cm layer of gravel with drainpipes, which led the percolate to a reservoir. The biobed was closed in the bottom by a membrane of bentonite with a plastic membrane underneath. The model biobed was filled on 14 June 1996. Grass was sown on the surface but did not establish well. Instead a grass turf, from an established grass field, was established on 16 April 1997 after the first winter period. A schematic presentation of the biobed is shown in Fig. 3.

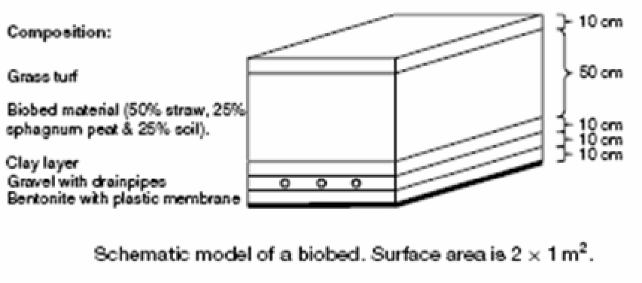

Fig. 3 Schematic model of the biobed used in the Danish study (Henriksen 2003)

The study revealed that the clay membrane could not retain the percolate and in the summer time 46% of the applied water was collected as percolate, while 90% passed the membrane in winter. Shortly after pesticide application some of the most mobile pesticides, bentazon, MCPA, mecropop and dimethoate, metribuzine and fluazifop were detected in the percolate. However, leaching was completely prevented when the biobed had a well-developed grass cover and was covered during the winter to prevent excess rain water coming into the biobed.

The English study was done in lysimeters (Fogg 2004). Two sets of lysimeters were prepared using PVC-piping (19 cm internal diameter x 75 cm length) with one end of the cut pipe sealed using a socket fitted with a drain outlet. Cores were filled with 2-3 cm gravel followed by 15 cm of washed sand. A 50-cm layer of biomix was packed in each lysimeter. The biomix was prepared by mixing topsoil, peat-free compost and unchopped winter barley straw in the proportions 1 + 1 + 2 by volume. The results showed that only the most mobile pesticides leached, and for these > 99% was removed by the system, with a significant proportion degraded within 9 months. Peak concentrations of the two most mobile pesticides did however exceeded the limits that are likely to be required by regulatory bodies.

Fig. 4 Lysimeters used in the English study (Fogg 2004). Observed the quality of the biomix showing mainly the unchopped straw.

Potential pesticide leaching in Swedish biobeds?

According to the Swedish studies in unlined biobeds most of the pesticides are retained in the upper 20 cm of the biobed and concentrations below the limit of detection are found in the clay layer suggesting no downwards transport of pesticides (Torstensson 2000).

However, recently Göran Ohlsson (Odling i balans) from Sjötorps, Norregård, Dalby constructed a lined biobed with an outlet to detect and store leakage water (Fig. 5). The profile of this biobed consisted of a plastic layer at the bottom followed by a macadam layer and then by a 10-cm layer of clay and 50-cm biomix. Finally a grass layer was put above. However, due to the poor establishment of the grass, water was added to the young biobed to promote growth. Short after a period with heavy rains arose. As a consequence of this combined situation water leaked from the biobed.

Samples of this water were taken in coordination with Eskil Nilsson, VISAVI, Göran Ohlsson and Lars Törner, Odling i Balans and analyzed. The results showed that pesticides as glyphosate and bentazon as well as the glyphosate metabolite AMPA were present (Table 1).

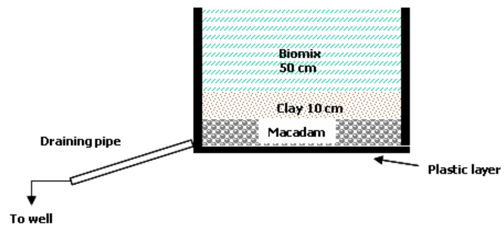

Fig. 5 Design of a lined biobed built at Göran Ohlsson´s farm

Table 1. Glyphosate, Bentazon and AMPA in leakage water from a lined biobed at Göran Ohlsson´s farm

	Bentazon (µg/l)	Glyphosate (µg/l)	AMPA (µg/l)
Sample 1	0,6	1,6	2
Sample 2	1	1,3	2
Sample 3	0,8	1	2

Because of this situation SLF approved the project H048153 which had the purpose to study the potential pesticide leaching from biobeds. The more detailed objectives were:

1. To evaluate the potential pesticide leaching in “normal” unlined biobeds,
2. To follow up the water and pesticide balance in two lined biobeds under normal use at the farms (no water from washing of the spraying equipment is included).

3. To study the potential leaching of water and pesticides when the biobeds are subjected to worst-case scenarios (water from washing of the spraying equipment and/or high precipitations).

Results from year 2006

Two questions are important to be answered:
Why were pesticides leaking in the lined biobed at Sjötorps Norregård, Dalby?
Are the biobeds in their original design leaking pesticides?

Hypotheses

Our hypothesis is that pesticides may leak from a biobed if conditions for preferential flow arises in the biomix and in the clay layer.

1. Preferential flow in the clay layer may occur when the clay is not wet and forms cracks.
2. Preferential flow in the biomix and pesticide leakage may occur when there is not an efficient mixing, large particles, low microbial activity and poor grass establishment. This situation is more critical in young biobeds.
3. A biobed may leak pesticides if both the biomix and the clay layer are not working properly.

Evaluations

To prove these hypotheses we studied two unlined and two lined biobeds. The selection criterion for the unlined biobeds was to observe the texture of the clay layer in biobeds with a natural clay soil at the bottom and another with an "added" clay layer. The criteria in the lined biobeds was to follow one biobed with a draining layer underneath the clay layer (with the consequent drying of the clay) compared to another in which we can be able to regulate the transport of water to the clay layer (wet sound clay).

Unlined biobeds

The two biobeds selected were at the farms of:

1. Gert Persson, Gessie, Vellinge – natural clay layer with non-chopped straw

   When sampling the biobed we observed a well wet and swelled clay layer. Samples of the upper layers of the biomix showed residues of the pesticides used at the beginning of the spraying season (Appendix Table 1-1). The samples were taken under the sprayer, the edges where the boom of the sprayer is located, at the area of handling of the concentrates and under the ramp. Significant levels where found under the ramp, sometimes higher than under the sprayer as in the case of isoproturon, difuflenican, deltamethrin, among others. This finding corroborates other studies showing that pesticides are retained at the wheels and washed out (ADAS, undated, River Cherwell Catchment Monitoring Study 1998-2000). This also corroborates our observations that very often there is no grass layer under the driving ramp probably due to spills of pesticides. Another observation is that clopyralid (0.01 – 0.02 μg/g) and benazolin (0.02 – 0.04 μg/g) were found at the upper parts of the clay layer which means that the biomix was not able to retain these pesticides efficiently. The use of unchopped straw reduces the absorption capacity and the microbial activity enhancing the transport of pesticides by preferential flow.
2. Björn Jacobsson, Stamgård, Tygelsjö – "artificial" added clay layer.

   The profile of this biobed consisted of a natural clay layer at 88 cm height, followed by a straw layer, another clay layer at a height of 65 cm and then straw, peat and soil added in layers and not as a mixture. As a consequence of this wrong design we found esfenvalerat (0.0004 μg/g) and pirimicarb (0.007 μg/g) residues at the 65-cm clay layer. Also, 0.0001 μg/g of esfenvalerat were still found in the upper parts of the deeper clay layer at 88 cm. Again the wrong construction of the biobed with the materials in layers and not as a mixture generated the transport of the pesticides through the biobed. Moreover, the clay layer at 65 cm may have been drained by the presence of the straw below allowing the following transport of the pesticides. The clay layer at 88 cm height was perfectly wet and swelled so further transport of pesticides may have been avoided.

Lined biobeds

Two lined biobeds are now available. One is the biobed at Göran Ohlsson´s farm (Fig. 5) and the second is the one at Gert Persson´s farm which was rebuilt.

1. Göran Ohlsson´s biobed

   The profile of this biobed is shown in Fig. 5. A macadam layer is placed above the plastic layer, followed by 10-cm clay layer, the biomix and the grass layer. Table 2-1 in the Appendix 2 shows the results of the analysis of the water leaked from the biobed and stored in the well. Besides glyphosate and AMPA other pesticide residues were found. Bentazon was the one appearing at higher concentration (20 µg/l). The leakage of pesticides in this biobed occurred when the biobed was young and the grass layer had not established yet. Exactly the same conditions as the Danish model biobed. Moreover, both biobeds had a draining layer of macadam or gravel that may have altered the humidity of the clay layer and enhanced formation of cracks. This may explain the appearance of pesticide residues in the leakage water. According to the Danish studies the leakage was stopped after a year probably when the grass layer was established and the biomix was more mature.

2. Gert Persson´s biobed

   The profile of this biobed is the one shown in Fig. 6. The biobed has a 10-cm sand layer over the plastic, followed by a 13-cm layer of clay, a 50-cm layer of biomix and the grass at the upper part. The draining pipe is placed at the interphase of the clay and the sand. A water seal is attach to the draining pipe and allows the regulation of the water level inside the biobed. The idea behind this is that the level of water could be adjusted so the clay will be always supply of water from the sand layer. Another important consideration taken into account in this biobed is that the biomix was carefully prepared to try to avoid or reduce the risks of leakage in young biobeds. The straw was chopped and the biomix was carefully mixed. Moreover a layer of old biomix was placed in the middle of the bed to as an inoculum. The biobed was used shortly after it was rebuilt and pesticide residues were found in the leakage water, especially clopyralid (15 µg/l), benazolin (3.5 µg/l) and glyphosate (1 µg/l). As in the other cases the combination of a young biobed and a grass layer not yet established seems to be very sensitive for the risk of pesticide leakage. Also, the wetting and swelling of the clay layer may not have been fully developed (because of little rain at that period) and allowed the transport of the pesticides. Eventhough that the biomix was well prepared it was still not efficient for retaining the pesticides.

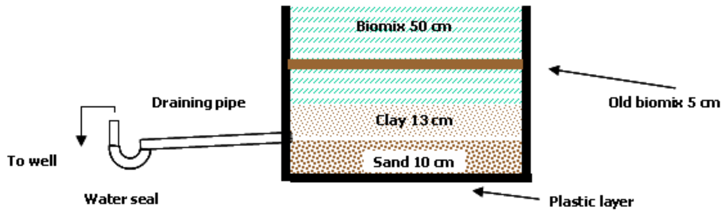

Fig. 6 Lined biobed at Gert Persson´s farm

Other observations

The purpose of this project has been mainly to study the risk for leakage of pesticides from biobeds however we have been able to make other observations that are important for a good management of the pesticides:

- The materials of the biomix have been added in layers and not as a mixture with the consequent risk for reduction in sorption capacity and microbial activity.
- The area of the biobed is too small and the management of the concentrates is done outside the biobed. This is the case we found at the Stamgård´s farm where a table with the concentrates was placed outside the biobed. Samples taken from the soil under the table showed pesticide residues at the same level as those found in the biobed under the sprayer (Table 1-2 Appendix 1). In this case the situation was not so serious because the table was on an active soil.
- Other materials than straw are used in the biobed as *Salix* residues that may affect the homogeneity of the mixture if added as long pieces.
- The area underneath the driving ramp has pesticide residues of the same order of magnitude as the area under the sprayer because of the wash out of the chemicals from the wheels (Tables in Appendix 1). It has been observed that the grass layer in this area is not repaired as often as other areas of the biobed. This could increase the risk for altering the water balance and the transport of the pesticides downwards.

Discussion

Preferential flow in the biomix and pesticide leakage may occur when there is not an efficient mixing, large particles, low microbial activity and poor grass establishment. This situation is more critical in young biobeds. The Danish and English studies and the results from Göran Ohlsson´s lined biobed corroborate this fact because all of them were dealing with young biobeds and with a poor grass growth. The effect of large particle size was more dramatic in the English study where non-chopped straw was used (see Fig. 4). Our hypothesis is that the texture of the biomix and the sorption capacity is enhanced with time as a function of the more extensive microbial activity and the degradation of organic matter. However, because higher risk for leakage occurs in young biobeds optimal conditions must been given from the beginning. What do we mean by optimal conditions in a young biobed/biomix? A more homogenous mixture, with straw of shorter particle size and with an active microflora.

Preferential flow in the clay layer may occur when the clay is not wet and forms cracks.
The clay layer should be wet and swell to avoid formation of cracks. Natural clays are normally provided of water by capillary forces coming upwards from the soil. If a draining layer is located below the clay the water transport is stopped and the clay will dry. This effect is more evident in lined biobeds where a draining- (as macadam or gravel) and an impermeable layer prevents the wetting of the clay. Hence, leaking through the clay layer of a biobed is an artifact of the design of lined biobeds. However, wrong construction of biobeds with the original design may also cause draining of the clay layer and risk for drying and formation of cracks. This is the case of the unlined biobed at Stamgård where a straw was placed under the clay layer. The question is could we reduce totally the risk for leakage by regulating the humidity in the clay layer? The drying of the clay layer may occur in unlined biobeds if they are located at places with rough material, i.e. if the clay layer is placed on a natural soil rich in stones, gravel or other draining structures. This is something to be evaluated by doing a survey of the actual biobeds in use.

Conclusions

- A biobed may leak pesticides if both the biomix and the clay layer are not functioning properly.
- The texture of the biomix may change with maturity due to the activity of microorganisms and the degradation of the organic material. It is recommended to continue the studies in the lined biobeds to evaluate the effect of maturity of the biobed on the leakage of pesticides.
- Smaller straw particle size, more efficient mixing and precomposting of the biomix may enhanced its texture and reduce the risk for leakage in young biobeds.
- The effect of humidity in the clay layer should be also study carefully because it is the basis that will allow to establish if the original biobed design is safe. Evaluations at the lined biobed at Gert Persson´s farm will answer some of these questions.

Further studies are needed to:
1. Study different alternatives to reduce the risk of leakage in a young biomix by testing smaller straw particle size, better mixing and precomposting of the biomix.
2. Study the effect of maturity on the leakage of pesticides from a biomix. Does the leakage of pesticides disappear with time?
3. Study the potential leakage of pesticides from a biobed as a function of the humidity in the clay layer.
4. Study and optimize lined biobeds with recirculation in the cases where no clay is available or safe to use.
5. Make a survey of biobeds to evaluate if they are following the recommendations. Special attention will be done to the materials used, the size of the straw, size of the biobed, etc.

References

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Appendix 1 - Unlined biobeds

Table 1-1. Pesticides found in Gert Persson´s biobed at Gessie, Vellinge

Unlined biobed with a natural clay layer at the bottom μg/g)

Active substance	Biomix old	Biomix conc. area	Biomix ramp	Biomix edge boom	Clay sprayer	Clay conc. area	Clay ramp	Detection limit μg/g
aclonifen	nd	nd	nd	nd	nd	nd	nd	0.02
azoxystrobin	0.01	0.008	0.03	0.006	nd	nd	nd	0.002
chloridazon	0.006	0.01	0.008	0.01	nd	nd	nd	0.003
deltamethrin	0.0007	0.002	0.001	0.002	nd	nd	nd	0.0005
esfenvalerat	0.001	0.001	0.003	0.0006	nd	nd	nd	0.00005
ethofumesate	0.004	nd	0.02	nd	nd	nd	nd	0.003
phenmedipham	0.01	nd	0.04	nd	nd	nd	nd	0.010
isoproturon	0.002	0.01	0.03	0.001	nd	nd	nd	0.001
metamitron	nd	nd	nd	nd	nd	nd	nd	0.01
metazachlor	nd	nd	nd	nd	nd	nd	nd	0.006
pirimicarb	0.02	30	nd	0.02	nd	nd	nd	0.003
diflufenican	0.012	0.039	0.16	0.007	nd	nd	nd	0.0005
bentazon	nd	nd	nd	nd	nd	nd	nd	0.001
clopyralid	traces	0.01	traces	nd	0.01	0.02	0.01	0.002
fluroxipyr	traces	nd	traces	nd	nd		nd	0.001
MCPA	traces	nd	nd	nd	nd	nd	nd	0.001
benazolin	2	traces	nd	nd	0.04	nd	0.02	0.001
dicamba	nd	nd	nd	nd	nd	nd	nd	0.001
dichlorprop	nd	nd	nd	nd	nd	nd	nd	0.001
2,4-D	nd	nd	nd	nd	nd	nd	nd	0.001
mecoprop	nd	nd	nd	nd	nd	nd	nd	0.001
quinmerac	traces	traces	0.007	nd	nd	nd	nd	0.002
flamprop	nd	nd	nd	nd	nd	nd	nd	0.001

nd: not detected

Table 1-2. Pesticides found in Björn Jacobsson´s biobed at Stamgård, Tygelsjö

Unlined biobed with an artificial clay layer at the bottom μg/g)

Active substance	Biomix sprayer 20 cm	Biomix sprayer 40 cm	Biomix ramp	Clay sprayer 65 cm	Clay sprayer 88 cm	Soil under table	Detection limit μg/g
aclonifen	0.02	nd	0.1	nd	nd	0.03	0.01
azoxystrobin	0.2	nd	0.03	nd	nd	nd	0.01
chloridazon	nd	nd	0.1	nd	nd	0.01	0.01
cyprodinil	nd	nd	nd	nd	nd	nd	0.001
deltamethrin	0.02	0.01	0.01	nd	nd	0.04	0.001
difuflenican	nd	nd	nd	nd	nd	0.01	0.001
esfenvalerat	0.0003	0.02	0.0001	0.0004	0.0001	0.0003	0.00005
ethofumesate	nd	nd	nd	nd	nd	nd	0.005
phenmedipham	nd	nd	nd	nd	nd	nd	0.02
isoproturon	nd	nd	nd	nd	nd	nd	0.003
pirimicarb	0.1	0.05	0.009	0.007	nd	0.02	0.005
propiconazole	nd	nd	nd	nd	nd	nd	0.005
benazolin	nd	nd	nd	nd	nd	nd	0.0003
bentazon	nd	nd	nd	nd	nd	nd	0.0003
clopyralid	nd	nd	nd	nd	nd	nd	0.004
fluroxipyr	nd	0.0009	nd	nd	nd	nd	0.0005
MCPA	nd	nd	nd	nd	nd	nd	0.0005
quinmerac	nd	nd	nd	nd	nd	nd	0.01

nd not detected

Appendix 2 - Lined biobeds

Table 2-1. Pesticides found in the drainage water of a young lined biobed (clay and macadam bottom)
Göran Ohlsson´s farm, Sjöstorps Norregård, Dalby (μg/l)

Sample 1, 2 and 3 Water sample taken directly from the draining pipe
Sample 4, 5 and 6 Water from the well

Active substance	Sample 1 03-Oct-05	Sample 2 05-Nov-05	Sample 3 03-Dec-05	Sample 4 23-Dec-05	Sample 5 23-Dec-05	Sample 6 23-Dec-05	Detection limit μg/l
Bentazon	20	1	0.5	0.6	1	0.8	0.02 - 0.04
Fluroxypyr	0.8	nd	nd	nd	nd	nd	0.02 - 0.05
Clopyralid	1.5	0.2	nd	traces	traces	traces	0.07 - 0.1
Quinmerac	nd	nd	nd	nd	nd	nd	0.06 - 0.1
MCPA	nd	nd	nd	nd	nd	nd	0.1 - 0.2
Mecoprop *	0.1	nd	nd				0.02
Glyphosate	2.3	0.12	0.11	1.6	1.3	1	0.02
AMPA	1.2	0.72	0.5	2	2	2	0.3
Amidosulfuron	0.8	0.1	traces	traces	traces	traces	0.06
Flupyrsulfuron-methyl-sodium	nd	nd	nd	nd	nd	nd	0.06
Iodosulfuron-methyl-sodium	nd	nd	nd	nd	nd	nd	0.06
Metsulfuron-methyl	0.2	nd	nd	nd	nd	nd	0.1
Sulfosulfuron	nd	nd	nd	nd	nd	nd	0.06
Tribenuron-methyl	nd	nd	nd	nd	nd	nd	0.05
Azoxystrobin	nd	nd	nd	nd	nd	nd	0.03 - 0.08
Diflufenican	traces	nd	nd	traces	traces	traces	0.005 - 0.01
Esfenvalerat	nd	nd	nd	nd	nd	nd	0.05
Fenitrothion	nd	nd	nd	nd	nd	nd	0.02
Fenpropimorph	nd	nd	nd	nd	nd	nd	0.01
Flurtamone	nd	nd	nd	nd	nd	nd	0.05 - 0.08
Metazachlor	traces	nd	nd	nd	nd	nd	0.02 - 0.03
Propiconazole	traces	nd	nd	nd	nd	nd	0.04 - 0.05
Prosulfocarb	nd	nd	nd	nd	nd	nd	0.01 - 0.02
Pyraclostrobin	nd	nd	nd	nd	nd	nd	0.1 - 0.3

nd: not detected

Table 2-2. Pesticides found in the drainage water of a young lined biobed (clay and sand bottom)
Gert Persson´s farm at Gessie, Vellinge
(μ**g/l)**

Active substance	Water from drainage well μg/l	Detection limit μg/l
chloridazon	traces	0.02
ethofumesate	traces	0.006
isoproturon	traces	0.005
metamitron	0.07	0.01
benazolin	3.5±3	0.008
bentazon	0.038 ± 0.006	0.008
clopyralid	15 ± 3	0.01
fluroxipyr	traces	0.008
MCPA	0.11 ± 0.02	0.008
quinmerac	0.068 ± 0.02	0.01
fluazinam	traces	0.001
tribenuronmethyl	traces	0.09
glyphosate	1 ± 0.2	0.1