EFFECT OF PHOSPHORUS IN SEWAGE SLUDGE ON PHOSPHORUS IN CROPS AND DRAINAGE WATER

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ABSTRACT

From two previously air-dried sewage sludges, one with a low and the other with a high heavy metal content, by leaching in monthly intervals, so as to produce an amount of drainage water equivalent to the annual precipitation surplus in the Netherlands (300 mm), phosphorus removal in a six year period was 0.25 and 0.06% respectively, pointing to a low mobility of P in sewage sludge under these conditions, especially in the sludge with the high heavy metal content.

From six previously air-dried sewage sludges, used as plant substrates, P removal by leaching in a seven year period was of the same order, except when the drainage water was more or less acid and P was much more mobile. In general, P removal by crops was much greater (4 - 20 times) than by leaching. Crop yields on the sludge substrates were high, except when heavy metal contents and mobility were high. For one sludge this resulted in a strong reduction in crop growth and P uptake. Mixing of one of the sludges (from domestic waste waters) with a sandy soil or a clay soil resulted in an increased percentage of sludge P taken up by crops, although even with only 5% sludge in the mixture, uptake of sludge P in a seven year period was no more than 8 - 10% of the initial amount of P in sludge (less than 1.5% per year).

Uptake of P from liquid sludges, applied every year since 1972 in amounts ranging from 7½ to 22½ tons. DM/ha/year, varied from 15 to 10% for grassland, and from 21 to 14% for arable land, depending on the amount of sludge applied. For the sludge with high heavy metal content, however, values for arable land were lower in the last years because of negative yield effects, owing almost certainly to the heavy metals in this sludge. For fertiliser P an uptake of 20% was assumed. No leaching of phosphorus from the liquid sludge was observed.

INTRODUCTION

Besides experiments aimed directly at the evaluation of sewage sludge as phosphate fertiliser (De Haan, this seminar), there are a number of more comprehensive experiments at our institute in which various aspects of the utilisation of sewage sludge as organic fertiliser, soil amendment or substrate for plant growth, have been studied. These experiments provided additional data about plant availability and leachability of phosphate in sewage sludge, which will be presented in this paper. The experiments are discussed separately below.

1. EXPERIMENT WITH TWO SEWAGE SLUDGES, LEACHED AT MONTHLY INTERVALS, AFTER HAVING BEEN AIR-DRIED IN 1973, TO STUDY THE CHANGES IN THE CHEMICAL COMPOSITION OF THE DRAINAGE WATER IN THE COURSE OF TIME

For this experiment, 140 litre vessels were used with a surface area of 0.2 m^2 and a depth of 0.7 m. Just above the bottom of the vessel there was an outlet for the drainage water and on the bottom a 5 cm gravel layer, covered by a nylon sheet, on which the sludge was placed.

Before being put into the vessels, the sludges had been on drying fields for about three months, followed by air-drying and shredding. One of the sludges (Leeuwarden) had a low, the other (Heerenveen) a high heavy metal content. The P contents (as P_2O_5) were 5.00 and 6.23%, respectively, corresponding to about 143 000 and 178 000 kg/ha, respectively. Every month the sludges were given enough demineralised water, to allow collection of about 5 litres of drainage water per vessel per month, resulting in an annual amount equal to the mean precipitation surplus in the Netherlands (300 mm). The drainage water was analysed monthly for pH, COD and EC, and every three months also for macro- and micro-elements.

The P concentrations in the drainage water have been plotted against time of collection in Figure 1. Concentrations drop from a rather high level in the first years to a rather low level in recent years. The level was lower for Heerenveen, notwithstanding a higher P content of the sludge.

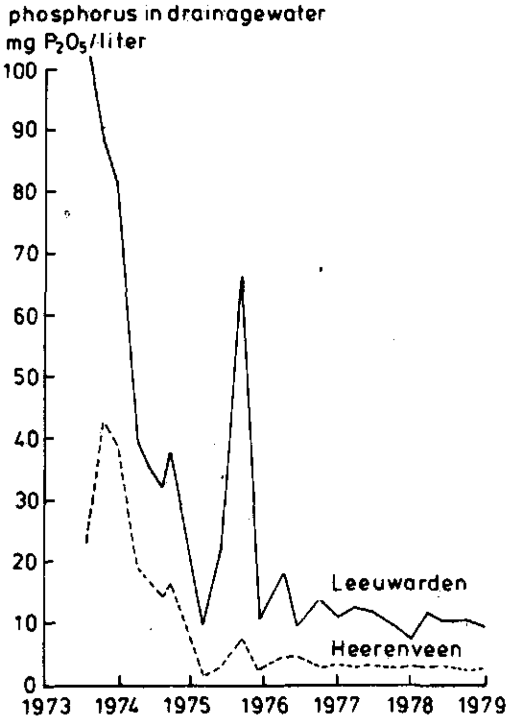

Fig. 1. Concentrations of phosphorus in drainage water from previously air-dried sewage sludge in the course of time.

Cumulative amounts of P in the drainage water on a hectare basis are presented in Figure 2. In the period June 1973 - December 1978 about 400 kg P_2O_5/ha was leached from the sludge from Leeuwarden and about 100 kg/ha from the sludge from Heerenveen, being about 0.25 and 0.06%, respectively, of the original amount of P in the sludges. Corresponding figures for nitrogen in the sludges were 13 and 5%, respectively (De Haan, 1980). This points to a low mobility of P in sewage sludge compared with N.

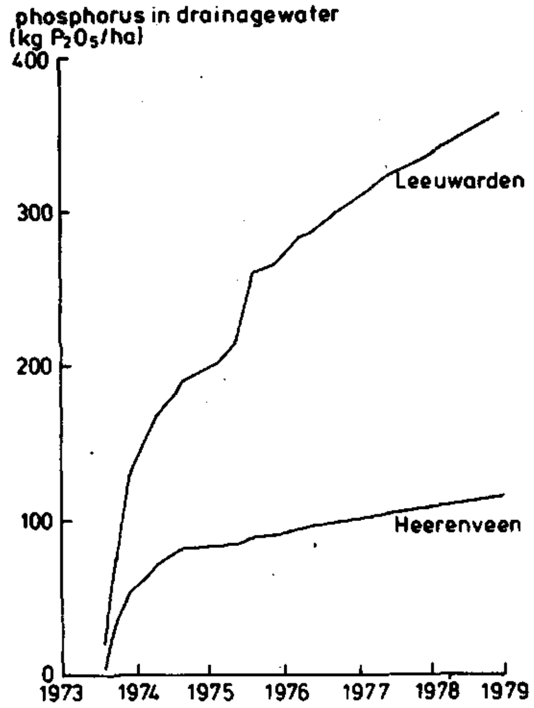

Fig. 2. Cumulative amounts of phosphorus in drainage water from previously air-dried sewage sludges.

The pattern of release for P from the two sludges is rather similar to that for N; with regard to N, the lower mobility of P in the Heerenveen sludge might be due to a lower decomposition rate of the organic matter in this sludge, and this again could be related to the higher heavy metal content of this sludge.

In the next experiment we will see that an acid reaction of the drainage water from the sludge was accompanied by a high mobility of the sludge-P, but this could not be the reason for a higher mobility of P in the Leeuwarden sludge, because pH values of the drainage water for this sludge, as for the Heerenveen sludge, have been > 7 up to now.

2. EXPERIMENT WITH SIX AIR-DRIED SEWAGE SLUDGES AS PLANT SUBSTRATES

This experiment has been in progress since 1972 and is carried out in the same way as the previous one, with the exception that now crops are grown on the substrates. The crops were: 1972 mustard, 1973 grass (six cuts), 1974 maize, 1975 sugar beet, 1976 potatoes, 1977 in succesion spinach, dwarf beans and radish and 1978 in succesion lettuce and celery. Crops have been analysed for macro- and micro-elements, except for the grains of mustard in 1972 and the straw of the beans and the leaves of the radish in 1977. The contents of P in these parts of the crop have been estimated on the basis of the best available knowledge. The drainage water has been analysed for the same characteristics as in the first experiment, once or twice a year, except in 1974, when no analyses were made. Values for this year have been estimated as intermediate between 1973 and 1975.

As the sludges were part of an experiment with normal soils, they were supplied with mineral fertilisers as these soils were, though in the first years a reduction was made for N and P in the sludges. In the 1972/78 period, mineral P was supplied on the basis of 830 kg P_2O_5 per hectare in addition to amounts of 164 000, 56 150, 149 000, 79 100, 148 500 and 134 300 kg/ha in the sludges, which were from the towns of Leeuwarden, Apeldoorn, Leiden, Eindhoven, Assen and Heerlen, respectively.

Cumulative amounts of P in crops and drainage water for the 1972/78 period are presented in Figure 3. It is clear from this Figure that there are large differences among the sludges. With the crops grown on the sludge from Leeuwarden nearly 3 000 kg P_2O_5 was removed per ha, or on average, about 400 kg/year. That is an enormous amount, due to the large P supply, but also to the fact that uptake per unit of surface area is always greater for pots than under field conditions, because crops in pots profit by the open space around the pots.

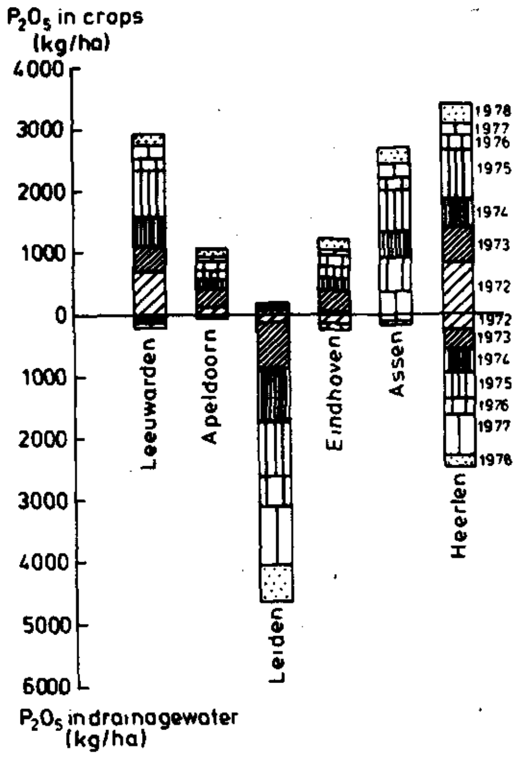

Fig. 3. Cumulative amounts of phosphorus in crops and drainage water from six air-dried sewage sludges in the period 1972/78.

The amounts of P in the crops are lower for the sludges from Apeldoorn, Leiden, Eindhoven and Assen than for the sludge from Leeuwarden. For the sludges from Apeldoorn, Eindhoven and Assen this is in accordance with the P content of the sludges, but not for the sludge from Leiden, where P uptake by crops was extremely low. This was due to heavy metal effects. As far as there was any growth, crops showed severe symptoms of excess heavy metals, especially nickel.

P removal by crops was largest for the sludge from Heerlen and from this sludge also an enormous amount of P (2 500 kg P_2O_5/ha in seven years) disappeared with the drainage water. The only explanation for this phenomenon is the acid reaction of the drainage water from this sludge. The validity of this explanation is strengthened by the fact that a still larger amount of P in the drainage water from the sludge from Leiden is accompanied by a still lower pH of this drainage water. Of course, the large amount of P in the drainage water from the sludge from Leiden may be due in part to the low amount taken up by the crop, but from the amounts of P in the drainage water from the other sludges it can be concluded that this factor had little effect, because for these sludges the amounts of P in the drainage water are quite comparable with those in the drainage water from the sludges left fallow in the previous experiment.

Table 1 gives the amounts of P in the crops and the drainage water in the period 1972/78 as percentages of the amount of P in the sludges; allowance having been made for an uptake by the crops of 20% of the P supplied in mineral form. The exceptional behaviour of the sludges from Leiden and Heerlen is evident again from this Table. There is not much difference among the other sludges. In a relative sense, very little of the sludge-P has been removed in this length of time and for the normal sludges this is especially true for P removed with drainage water.

TABLE 1

PHOSPHORUS REMOVED BY CROPS AND DRAINAGE WATER FROM AIR-DRIED SEWAGE SLUDGES, USED AS PLANT SUBSTRATES, IN THE PERIOD 1972/78, IN % OF PHOSPHORUS IN THE SLUDGES

Sludge	Leeuwarden	Apeldoorn	Leiden	Eindhoven	Assen	Heerlen
Crops	1.69	1.65	0.01	1.33	1.71	2.38
Drainage water	0.13	0.08	3.09	0.33	0.12	1.82
Sum	1.82	1.73	3.10	1.66	1.83	4.20

3. MIXTURES OF SOILS AND AIR-DRIED SEWAGE SLUDGE

The sludge from Leeuwarden, a sludge from mainly domestic waste waters, was mixed with a light sandy soil and a heavy clay soil in the following soil/sludge ratios: 100/0, 95/5, 90/10, 80/20, 60/40, 30/70 and 0/100. This experiment was conducted in the same way as was described under 2, except that more P (and N) as fertiliser was supplied as the proportion of soil in the mixture increased. The amounts of fertiliser P as P_2O_5 over the 1972/78 period were, in the order of the soil/sludge ratios mentioned above, 930, 925, 920, 910, 890, 860 and 830 kg/ha. The sandy soil contained, on a hectare basis, 8 800 kg P_2O_5, the clay soil 12 100 kg.

Cumulative amounts of P, taken up by the crops and leached with the drainage water in the 1972/78 period are presented in Figure 4. With increasing proportions of sludge in the mixture, there is a strong increase in the amount of P in the crops, due to an increase in the yields as well as in the P concentrations of the crops. There is a similar effect on the amount of P in the drainage water, but much less pronounced. In comparison with the crops, the amount of P in the drainage water is very low, in contrast with nitrogen (De Haan, 1980).

In Table 2, P in crops and drainage water, originating from the sludge in the 1972/78 period, is expressed in % of the P in the sludge at the beginning of the experiment, both for the sandy and the clay soil/sludge mixtures. To calculate these figures, for fertiliser P an uptake of 20% by the crops and no leaching has been assumed. Then for soil P, rates of 2.7 and 7.0% for plant uptake and 0.15 and 0.13% for leaching could be calculated for the sandy and clay soil, respectively, and then for sludge P the values of Table 2. It is evident from this Table that the values for uptake by the crop increase with decreasing proportions of the sludge in the mixture, but even with 5% sludge in the mixture the value is rather low, namely about 9% in seven years. There are no great differences

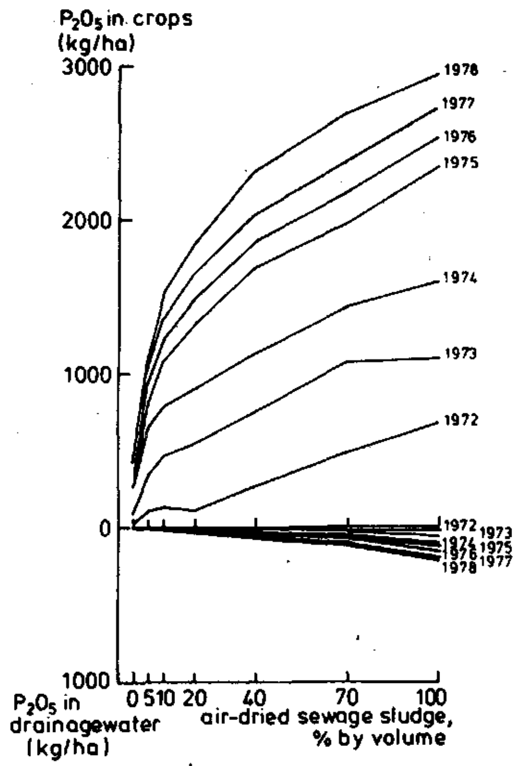

Fig. 4. Cumulative amounts of phosphorus in crops and drainage water from sandy soil/sewage sludge-mixtures in the period 1972/78.

TABLE 2

PERCENTAGE OF PHOSPHORUS, TAKEN UP BY CROPS AND LEACHED IN A SEVEN YEAR PERIOD FROM SEWAGE SLUDGE IN SOIL/SLUDGE-MIXTURES, AS DEPENDENT ON THE PERCENTAGE OF AIR-DRIED SEWAGE SLUDGE IN THE MIXTURE

% by vol. sewage sludge	0	5	10	20	40	70	100
	Sandy soil/sewage sludge-mixtures						
Crops	2.70*	8.34	6.85	4.46	3.05	2.12	1.69
Drainage water	0.15*	0.06	0.00	0.05	0.09	0.09	0.13
	Clay soil/sewage sludge-mixtures						
Crops	7.17*	9.89	7.29	4.09	2.99	2.06	1.69
Drainage water	0.13*	0.07	0.20	0.13	0.13	0.12	0.13

* Values for soil P

among the soils, but at the lower sludge rates, values are lower for the sandy soil/sludge mixtures, both for uptake by the crop and leaching, and there might be some fixation of sludge P by the sandy soil.

4. LIQUID SEWAGE SLUDGES AS ORGANIC FERTILISERS FOR GRASSLAND AND ARABLE LAND

Two sludges, from the towns of Almelo and Alkmaar, respectively, were applied in amounts of 0, 7½, 15 and 22½ tons. DM/ha/year since 1972 to a sandy soil in vessels as described earlier. The sludge from Almelo has a rather high heavy metal content, especially Cd, Cu and Ni; the sludge from Alkmaar is from mainly domestic waste water. It is the intention to apply the sludges in ten successive years, in order to create a situation which in practice, when sludge is applied, will arise only in a minimum of 100 years, because of an agreement stipulating that sludge will not be applied in amounts larger than 2 tons DM/ha/year.

Half the number of vessels are treated as grassland and the other half as arable land, with the same crops as in the previous experiments, except 1973, when maize was grown instead of grass. N and P application in mineral form was reduced in accordance with the amounts of sludge applied. In the 1972/78 period the amounts of fertiliser P applied as P_2O_5 in kg/ha were 1 080, 780, 480 and 180 for grassland and 1 020, 713, 407 and 100 for arable land at sludge application rates of 0, 7½, 15 and 22½ tons DM/ha/year, respectively. The amounts of P in kg/ha P_2O_5, applied as sludge, were 0, 3 176, 6 535 and 9 529 for the sludge from Almelo and 0, 2 378, 4 757 and 7 135 for the sludge from Alkmaar. The soil contained 8 800 kg P_2O_5 per ha.

Figure 5 presents cumulative amounts of P in grass and drainage water from the grassland over the 1972/78 period. It is evident from this figure that P uptake by grass was promoted more by the sludge from Almelo than by the sludge from Alkmaar.

There was no effect of sludge application on the amount of P in the drainage water, which was very low (less than 20 kg/ha in seven years). It should be noticed that in this experiment sludge was not mixed through the whole profile, but in the case of grassland it was applied on top of the sod, which was broken up every two or three years and mixed through the upper 20 cm of the 60 cm deep profile. Sub-soil and top-soil were the same. In the case of arable land, sludge was always mixed through the 20 cm top layer.

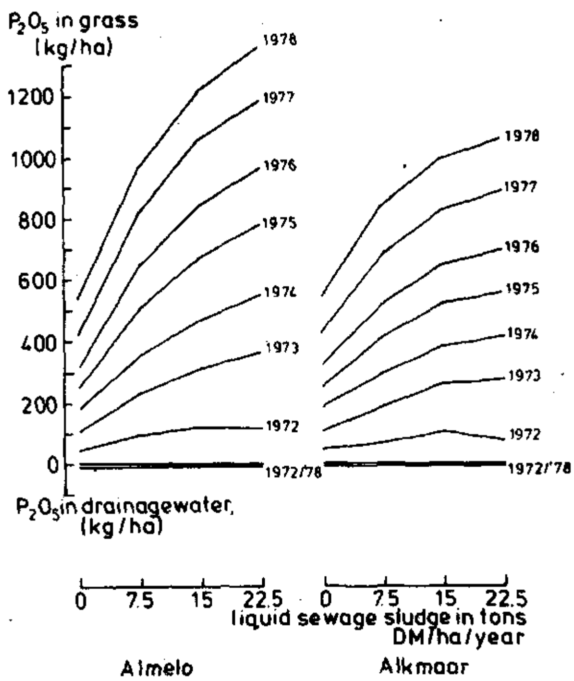

Fig. 5. Amount of phosphorus in grass and drainage water from permanent grassland, cumulative over the period 1972/78.

The effect of sludge application on the amount of P in the crops and drainage water from the arable soil is presented in Figure 6. Here the first experimental year is left out of consideration, because no crop analyses were made in this year. It appears from Figure 6 that in 1973 and 1974 P uptake by crops was increased more by the Almelo than by the Alkmaar sludge, but in the following years it was just the reverse, because of negative effects on yields, due almost certainly to the heavy metals, especially nickel, in the Almelo sludge. Also for arable land there was no effect of sewage sludge on the amount of P in the drainage water.

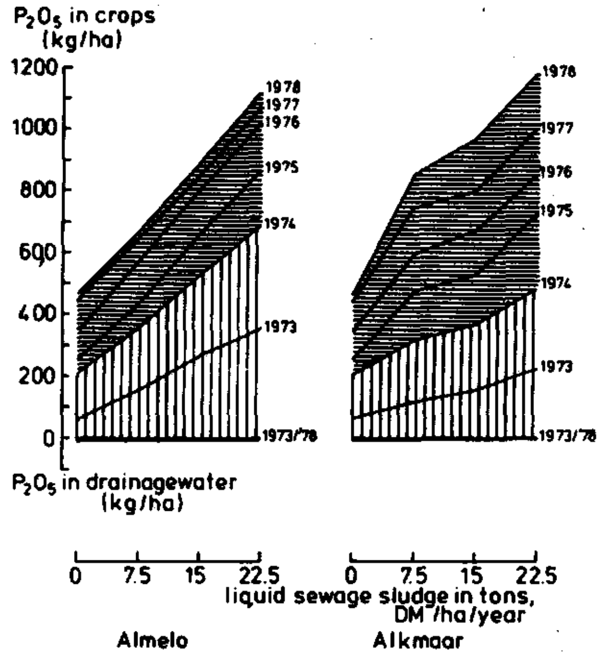

Fig. 6. Amount of phosphorus in crops and drainage water from arable land, cumulative over the period 1973/78.

Table 3 presents percentages of P taken up by the crops from the sewage sludges in the 1972/78 period for grassland and the 1973/78 period for arable land, assuming an uptake of 20% for fertiliser P and no effect of sludge on uptake of soil P. On grassland, 15 to 10% of sludge P was taken up by the crop depending on the sludge application rate. For arable land the percentages were higher for the sludge from Alkmaar, but lower for the sludge from Almelo. In comparison with the previous experiments, values for uptake of sludge P are rather high, varying from 50 - 100% of the (assumed) value for fertiliser P.

TABLE 3

MEAN VALUES FOR PERCENTAGES OF PHOSPHORUS FROM SEWAGE SLUDGES, TAKEN UP BY CROPS IN THE PERIOD 1972/78 FOR GRASSLAND AND 1973/78 FOR ARABLE LAND

Sewage sludge	Almelo			Alkmaar		
Amount, t DM/ha/year	7½	15	22½	7½	15	22½
Grassland	15.1	12.6	10.5	14.9	12.0	9.8
Arable land	9.1	9.6	9.8	21.1	14.6	14.2

REFERENCE

Haan, S. de, 1980. Effect of nitrogen in sewage sludge on nitrogen in crops and drainage water. Report on the 2nd Session of Working Party 4 of the EEC Concerted Action Treatment and Use of Sewage Sludges in Dijon 26/28 September 1979.

DISCUSSION

R.E. White *(UK)*

In your Figure 2 you suggested that the lower leaching of phosphorus from the one sewage sludge was due to its high heavy metal content: are you suggesting that heavy metals immobilise phosphate in the sludge, and what kind of heavy metals are they?

Secondly, in Figure 3 where you had high leaching from two of your sludges, you said that this was due to the acid drainage water. Can you tell us how acid the drainage water was, what was the pH?

S. de Haan *(Netherlands)*

On the last question, in that case the pH was 6; the others were all 7 or above.

On the first question, the same applied for nitrogen and for phosphorus in that particular case - the amount of nitrogen leached was much lower than with the other sludges. So it could be due to prevention of decomposition of the organic matter by these heavy metals but on the other hand, most of the phosphate in the sewage sludge is not in organic form so from that point of view it seems unlikely.

A. Dam Kofoed *(Denmark)*

I was interested to learn from Dr. de Haan that you use the word 'drainage water' for a surface area of 0.2 m^2 and a depth of 0.7 m. Would it not be more correct to talk about 'leaching water' because drainage water really means water that comes through a drain, as I understand it. I think it might be confusing.

S. de Haan

The experiment was set up so that we got as much drainage water as the normal precipitation surplus, about 300 mm. I had a small outlet, but I think it is more percolation water or leachate - it may be a question of language.

A. Cottenie *(Belgium)*

I think it is also a question of technique. You might have analysed the drainage water or the percolation water - it is not the same.

S. de Haan

I took it from the ditch.

A. Cottenie

Leaching water.