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Oxygen demand of waters associated with the use of sewage sludge compost and limestone outcrop as a filtration system

Ana Pérez Gimeno [a], Jose Navarro Pedreño [a, **], María Belén Almendro Candel [a], Ignacio Gómez Lucas [a], Antonis A. Zorpas [b, *]

[a] Department of Agrochemistry and Environment, Miguel Hernández University of Elche, Av. de la Universidad, s/n, 03202 Elche (Alicante), Spain
[b] Open University of Cyprus, Faculty of Pure and Applied Sciences, Environmental Conservation and Management, Lab of Chemical Engineering and Engineering Sustainability, P.O. Box 12794, 2252, Latsia, Nicosia, Cyprus

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ABSTRACT

The use of composted sewage sludge (SW) and limestone outcrop residue (LR) as water filter systems has been tested. An experimental design based on the use of columns (0−30 cm) was used with both wastes under a heavy irrigation regime (2000 mL/week) for 12 weeks. Half of them were irrigated with nonsaline water (NS) and the others with saline water (S). Four treatments combining the quality of the irrigation water and wastes were obtained: SW-NS, SW-S, LR-NS, and LR-S. The chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), and suspended solids were measured. The results indicated that COD and BOD_5 were higher in the treatments with SW than LR, whereas saline irrigation did not modify BOD_5 compared with nonsaline irrigation, but COD increased in both wastes. The environmental concern due to organic matter displacement in waters should be taken into account when using these wastes, especially SW. Moreover, the use of S may increase the COD with the consequent risk for natural water. When designing a filter system considering inert and organic matter, SW and LR can be effective materials and should be taken into consideration.

1. Introduction

Sewage biosolids resulting from wastewaters are an inevitable byproduct of water cycle, and the total production is estimated to be more than 13 million tons of of dry solids before the end of 2020. Sewage sludge may be used as a resource in many sustainable ways instead of being considered and managed as a waste. An attention was given worldwide to the illegal disposal of sewage sludge because of its potential threat to people's health and environment in general [1,2]. The composted sewage sludge (SW) and limestone outcrop residues (LRs) are commonly used in land rehabilitation, soil improvement, and techno sol making and can influence the mobility of organic compounds into groundwater [3–5]. Composting has become one of the main sustainable options to be applied for sewage sludge treatment [6,7] because of less cost and recycling of nutrient-rich organic fertilizers [8]. These treatments are particularly suitable for certain soils and allow applications to land over different times or terrains than otherwise would be the case.

In addition, organic and inorganic wastes can be used in urban sustainable drainage systems, green filters, and for phytoremediation purposes [9–11]. Landfill disposal of wastes is considered as a major and significant source of water pollution [12] because of the drainage and infiltration in the soil. These wastes can be responsible for the

* Corresponding author.
** Corresponding author.
E-mail addresses: jonavar@umh.es (J. Navarro Pedreño), antonis.zorpas@ouc.ac.cy, antoniszorpas@yahoo.com (A.A. Zorpas).

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organic pollution of waters, which can affect and modify the oxygen demand in surface waters, leachates, and groundwater. Dissolved organic matter (DOM) is mentioned as the main pollutant as it comprises a majority of organic substances in the leachates [13,14]. DOM is often regarded as a continuum of organic molecules of different molecular weights and structures including low molecular weight substances like humic substances and influence the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of waters [13]. Hence, with adequate oxygen and free airspace, decomposable organic matters and moisture content in the sludge are reduced, and the pathogens are inactivated by thermophilic condition [15].

Most of the experiments done to determine the pollution of waters based on the use of these wastes as filtration systems or amendment materials include (1) the presence of heavy metals in leachates [16–18], (2) the determination of nitrogen pollution [19,20], (3) some of them in the concentration of DOM [21,22], and (4) treating the leachates to reduce the presence of the organic matter [13,14,23].

The presence of DOM in leachates can affect COD and BOD as well as the content of suspended solids (SSs), which can be related to turbidity, total solids, and total dissolved solids of water [24]. Furthermore, some experiments showed the possibility of using organic materials in coagulation–flocculation processes to reduce the presence of SSs [25]. However, organic matter in filtration systems can also contribute to increase the presence of SSs in waters. In this sense, the possible use of organic wastes like sewage sludge and inorganic wastes like limestone outcrops, in filtration systems, should be studied considering these effects.

The objective of this work was to test the possible effects on oxygen demand of leachates because of the use of SW and LR as water filter systems. Furthermore, this research analyzes what happens when the source of water has high concentration of salts and if this affects COD and BOD of waters.

2. Materials and methods

An experimental design was applied to analyze the possible pollution derived from the use of SW and LR as filtration systems for waters was. The main physicochemical characteristics of both wastes are presented in Table 1.

SW has an important electrical conductivity, organic matter, and nutrient content (P and N), whereas LR (which is a mixture of calcium carbonate particles with a size less than 2 mm) has a great hydraulic conductivity (almost three times higher than SW).

Polymerizing vinyl chloride (PVC) columns (0–30 cm long and 10.5 cm of diameter) were filled with both wastes, softly hand compacted to fit the residues inside. Plastic containers were disposed under the columns to collect the leachates. The columns were submitted to a heavy irrigation regime by flood irrigation, and the amount of water applied was similar to a heavy storm in Mediterranean areas or flood irrigation for agricultural purposes. Sixteen columns (eight per waste, SW and LR) were irrigated once a week with 2000 mL/week (approximately equivalent to 230 mm) for 12 weeks (April–July). All of them were inside a greenhouse under controlled conditions of temperature (20 °C ±5) and air relative humidity (60% RH). Half of them

Table 1
Characteristics of the composted sewage sludge (SW) and limestone outcrop residue (LR).

Parameters	Units	SW		LR	
		Mean	SD	Mean	SD
⌀ > 2 mm	%	–	–	59.6	–
0.5 mm < ⌀ < 2 mm	%	–	–	21.8	–
0.063 mm < ⌀ < 0.5 mm	%	–	–	13.5	–
⌀ < 0.063 mm	%	–	–	5.0	–
Hydraulic conductivity	$cm^3 h^{-1}$	383.7	708.9	833.4	0
Bulk density	$g cm^{-3}$	0.5	–	1.6	–
pH_w	–	5.6	0.1	9.1	0.1
Electrical conductivity (25 °C)	$\mu S cm^{-1}$	9800.0[a]	52.3	67.8[b]	3.3
Total organic matter	%	68.0	1.3	1.1	0.1
Oxidizable organic matter	%	27.1	2.7	0.4	0.1
N Kjeldahl	%	2.5	0.1	0.018	0.002
Phosphorous	$g kg^{-1}$	21.7	0.8	0.996	0.366
Potassium	$mg kg^{-1}$	5413.2	151.6	1285.5	125.8
Sodium	$mg kg^{-1}$	5134.2	41.9	1025.2	79.0
Calcium	$g kg^{-1}$	5.0	0.1	293.3	13.9
Magnesium	$g kg^{-1}$	2.2	0.2	3.5	0.5
Iron	$g kg^{-1}$	3.7	0.2	10.0	2.5
Manganese	$mg kg^{-1}$	95.8	12.2	27.0	1.5
Copper	$mg kg^{-1}$	192.0	10.2	7.2	1.4
Zinc	$mg kg^{-1}$	640.5	22.3	31.5	1.1
Nickel	$mg kg^{-1}$	20.2	0.6	8.2	0.8
Chrome	$mg kg^{-1}$	30.6	0.8	16.8	1.7
Cadmium	$mg kg^{-1}$	0.6	0.1	0.3	0.1
Lead	$mg kg^{-1}$	71.5	7.4	1.4	0.2

Determinations done with dry wastes for all the parameters.
[a] Electrical conductivity in 1:10 w/v water extraction.
[b] Electrical conductivity in 1:5 w/v water extraction.

were irrigated with a nonsaline water (NS) and the others with saline water (S).

Four treatments (with four replicates) were established (SW-NS, SW-S, LR-NS, and LR-S) combining the quality of the irrigation water (S and NS) and the filters of wastes (SW and LR).

After 24 h of the irrigation on the first day of each week, the leachates were taken and analyzed directly. For COD, BOD_5, and total suspend solids (TSS), standard methods were applied [26]. COD was determined by oxidizing the organic matter of the sample with a mixture of strong acid solution (SO_4H_2) and potassium dichromate ($Cr_2O_7K_2$), and after that the remaining potassium dichromate was determined by titration with ferrous ammonium sulfate. BOD_5 was determined by filling with diluted and seeded sample an airtight bottle and incubating at 20 °C for 5 days, using titrimetric method. TSS were determined in a well-mixed sample filtered through a weighed standard glass-fiber filter and the residue retained on the filter was dried to a constant weight at 105 °C.

Table 2 presents the characteristics of the irrigation water (NS and S) used in this study.

The NS was a tap water with an average electrical conductivity of 0.8 mS/cm and a pH of 8.1, whereas S in this experiment was water from the Vinalopó river, used for instance in the irrigation systems of palm tree orchards with an electrical conductivity of 17.9 mS/cm and a pH of 8.2.

Descriptive statistics (mean value and standard deviation [SD]) and analysis of variance (ANOVA) *F* test of two ways were used to analyze the statistical significance of the results [27].

3. Results and discussion

The results are presented in Tables 3–5. In general, all parameters showed statistically significant differences using ANOVA *F* test, because of the type of irrigation water or because of the wastes used as filtration system. However, this was not reflected considering both factors most of the times (irrigation × wastes). COD and BOD_5 were higher in the SW than LR samples, as it was expected because of the low content of organic matter in the LR. COD was generally over 10 times higher in SW treatments than LR. The organic composition of the SW influenced the presence of DOM in the leachates [22] and can be responsible for the higher COD and BOD_5 measured in leachates from these treatments (SW-NS, SW-S).

The input of COD and BOD_5 due to the S was important (Table 2) but statistically, the type of waste was more determinant for the presence of COD and BOD in the leachates (Tables 3 and 4). Nevertheless, over the time, the differences between SW and LR were reduced considering the BOD_5 and the type of water used mainly affected SS. At the beginning of the experiment, no statistical differences were obtained but, from the middle to the end, water influenced clearly the content of SSs in leachates (Table 5) more than the type of waste used to fill the columns. The higher presence of SSs in the S (coming from the Vinalopó river) could control this parameter in the leachates after the first weeks.

It is important to check the differences between the inputs and outputs to determine if the wastes produced changes in the incoming water or not. Figs. 1–3 show the differences between outputs (leachates) and inputs (irrigation water) of COD, BOD_5, and SSs. A negative value means that the filter was efficient to reduce the parameter from the water and a positive value indicates increment in the parameter measured due to the waste.

On one hand, the filtration system with LR can reduce the BOD_5 and the SS, whereas on the other hand, the organic compost reduced the SS as far as the inorganic residue. It would be expectable that the reduction of SS can be increased along time, as other works indicated that the nature of landfill acts as a positive factor [28] and, this may be the process that happened when using these wastes as filters for long time. As the report from the DG Environment of the European Commission recommends [29], the use of this type of residues will follow the line of land rehabilitation when no risk of environmental pollution, especially water pollution, will occur.

However, the compost produced from sewage sludge helps to increase the oxygen demand (BOD_5, COD) within the sampling period. These results, attending only to the

Table 2
COD (mg O_2 L^{-1}), BDO_5 (mg O_2 L^{-1}), and SSs (mg L^{-}) determined in the irrigation water.

Week	NS			S		
	COD (mg O_2 L^{-1})	BDO_5 (mg O_2 L^{-1})	SS (mg L^{-1})	COD (mg O_2 L^{-1})	BDO_5 (mg O_2 L^{-1})	SS (mg L^{-1})
1	0.0	2	0.2	152.8	6	18.5
2	12.5	0	3.2	91.7	0	115.8
3	6.3	8	2.1	54.2	4	122.5
4	5.8	0	1.9	35.8	0	177.0
5	12.5	12	0.0	37.5	13	72.6
6	0.0	9	0.0	34.4	22	180.0
7	8.3	16	0.0	33.3	18	115.7
8	4.2	13	0.3	39.6	15	211.3
9	0.0	18	1.9	29.2	19	153.4
10	12.5	7	0.0	58.3	18	108.6
11	8.3	6	0.0	39.6	8	73.2
12	4.2	16	0.0	16.7	16	79.2
Mean	6.2	9	1	51.9	12	119.0
SD	4.8	6	1	36.9	8	54.7

Table 3
Chemical oxygen demand (mg O_2 L^{-1}).

Treatment		Week											
		1	2	3	4	5	6	7	8	9	10	11	12
SW-NS	Mean	428.5	684.9	674.0	301.0	496.4	442.7	429.2	291.7	315.6	399.0	238.0	215.6
	SD	*209.5*	*352.8*	*162.4*	*178.6*	*52.9*	*17.1*	*36.2*	*55.8*	*60.1*	*200.5*	*64.0*	*70.6*
SW-S	Mean	373.3	854.7	879.2	795.4	445.3	406.3	451.6	352.1	357.8	449.0	279.7	272.4
	SD	*325.3*	*615.5*	*331.7*	*347.8*	*107.4*	*123.5*	*125.4*	*26.7*	*153.2*	*157.0*	*15.1*	*61.5*
LR-NS	Mean	66.3	16.1	9.4	10.5	9.9	10.4	8.3	12.5	5.2	32.3	12.0	5.7
	SD	24.1	10.0	5.5	4.3	6.0	6.1	4.5	2.9	5.0	7.1	2.0	6.0
LR-S	Mean	147.6	68.8	22.9	36.4	41.1	37.2	41.1	46.4	27.6	56.3	43.2	25.0
	SD	*102.6*	*57.9*	*10.5*	*9.4*	*21.7*	*10.0*	*7.9*	*4.3*	*8.4*	*4.2*	*3.9*	*3.8*
F value ANOVA	Irrigation	0.5	0.4	1.4	7.1	0.1	0.1	1.6	9.3*	0.6	0.3	4.9*	2.6
	Waste	4.7*	16.7**	67.7***	28.8***	213.9***	163.7***	68.4***	355.2***	60.4***	35.5***	196.8***	94.8***
	Irrigation × Waste	0.0	0.1	1.1	5.7*	1.8	1.0	0.6	0.7	0.1	0.1	0.1	0.6

F value ANOVA : Descriptive statistics (mean value and standard deviation) and ANOVA F test of two ways were used to analyze the statistical significance of the results. * 95%, ** 99% and *** 99.9 %.

oxygen demand of waters (chemical and biological), indicate that sewage sludge may be a raw material that can act as a source of organic pollution for waters (surface or underground), although at the end of the experiment (3 months) the differences were reduced between both wastes, organic and inorganic. In this sense, the behavior of the SW filters may behave as an anaerobic reactor stimulated by the humidity and biological growth [30]. Moreover, within LR filters, biological activity along time may be increased due to the accumulation of filtered organic substances and can influence the properties measured.

In this short experiment, the trend of both filters cannot be well defined so far. However, they can be suffering processes of transformation into a “soil” or a growing media (edaphization processes) with an important biological activity, chemical reactivity, and changes that can favor the growth of organisms and the development of plants. In this case, the use as filtration systems can be changed and may be considered after long time like green filtration systems, where other factors like biota may be checked and can affect the composition of leachates. This fact will increase the organic matter content of the LR filters.

Table 4
Biological oxygen demand (mg O_2 L^{-1}).

Treatment		Week											
		1	2	3	4	5	6	7	8	9	10	11	12
SW-NS	Mean	41.5	7.0	19.8	13.8	22.0	22.0	22.8	14.8	22.3	16.8	17.8	18.3
	SD	*14.5*	*6.2*	*5.3*	*2.5*	*2.9*	*1.8*	*2.2*	*1.3*	*2.5*	*2.9*	*3.9*	*1.7*
SW-S	Mean	48.5	8.5	25.3	21.8	15.5	21.3	22.3	17.3	22.8	18.5	19.8	19.0
	SD	*15.3*	*4.4*	*9.6*	*15.7*	*6.1*	*3.9*	*3.0*	*2.5*	*4.2*	*5.0*	*1.0*	*3.5*
LR-NS	Mean	19.5	0.0	7.0	6.0	12.3	16.0	8.8	8.5	17.0	12.0	17.8	12.8
	SD	*7.2*	*0.0*	*4.6*	*4.0*	*5.6*	*4.8*	*0.5*	*5.8*	*4.0*	*6.0*	*1.5*	*5.6*
LR-S	Mean	20.0	0.0	9.3	7.5	11.0	15.0	16.5	13.3	13.5	15.3	14.3	14.3
	SD	*5.4*	*0.0*	*4.2*	*5.2*	*8.3*	*4.6*	*5.9*	*2.9*	*4.4*	*3.6*	*5.7*	*5.5*
F value ANOVA	Irrigation	0.4	0.2	1.5	2.4	1.7	0.2	4.2	4.2	0.6	1.2	0.2	0.3
	Waste	19.4***	16.5**	20.9***	7.5*	5.6*	9.6*	31.8***	8.5*	14.3**	3.1	2.4	5.5*
	Irrigation × Waste	0.3	0.2	0.3	1.4	0.8	0.0	5.6*	0.4	1.1	0.1	2.4	0.0

F value ANOVA : Descriptive statistics (mean value and standard deviation) and ANOVA F test of two ways were used to analyze the statistical significance of the results. * 95%, ** 99% and *** 99.9 %.

Table 5
Suspended solids (mg L^{-1}).

Treatment		Week											
		1	2	3	4	5	6	7	8	9	10	11	12
SW-NS	Mean	63.9	61.2	74.9	32.1	44.0	38.7	53.6	15.2	84.0	16.8	22.4	21.4
	SD	*25.5*	*24.0*	*34.0*	*14.4*	*26.1*	*4.6*	*10.7*	*8.8*	*29.6*	*14.1*	*11.4*	*9.0*
SW-S	Mean	155.1	140.5	144.4	153.3	59.8	98.4	91.5	57.2	110.4	67.7	74.7	82.8
	SD	*51.8*	*109.6*	*93.3*	*84.9*	*34.6*	*18.5*	*33.7*	*36.2*	*18.1*	*20.0*	*33.0*	*31.6*
LR-NS	Mean	53.6	60.9	161.4	88.9	35.7	11.9	17.4	5.0	36.1	6.7	9.5	4.7
	SD	*27.3*	*18.9*	*49.2*	*58.3*	*36.8*	*14.2*	*22.4*	*0.5*	*16.8*	*10.2*	*17.4*	*5.4*
LR-S	Mean	90.9	55.5	77.7	121.2	120.8	89.8	119.8	129.9	164.0	76.3	65.0	68.9
	SD	28.2	26.1	29.9	134.3	190.8	45.7	78.7	33.8	72.2	67.4	39.6	22.3
F value ANOVA	Irrigation	13.6*	1.6	0.1	3.3	1.0	28.5***	9.8**	60.0***	14.3**	10.9**	14.7**	39.4***
	Waste	4.5	2.1	0.1	0.1	0.3	1.8	0.0	0.1	0.1	0.0	0.6	2.3
	Irrigation × Waste	2.4	2.1	7.2*	1.1	0.5	0.5	2.0	1.0	6.2*	0.2	0.0	0.1

F value ANOVA : Descriptive statistics (mean value and standard deviation) and ANOVA F test of two ways were used to analyze the statistical significance of the results. * 95%, ** 99% and *** 99.9 %.

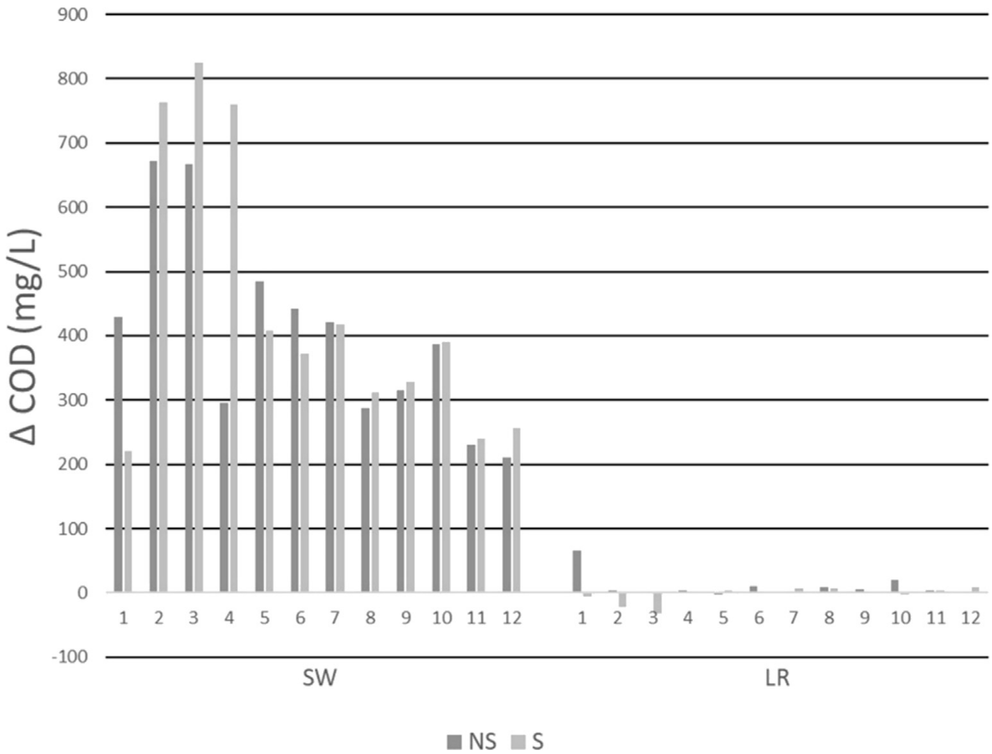

Fig. 1. Balance of COD between output water and input water.

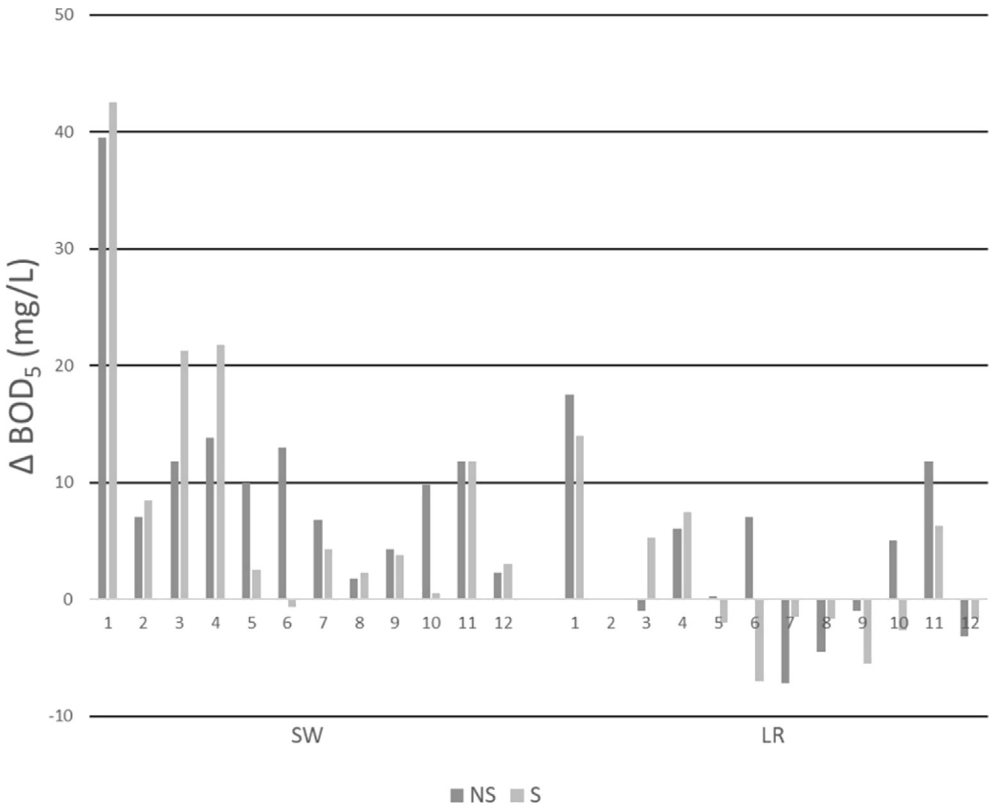

Fig. 2. Balance of BOD_5 between output water and input water.

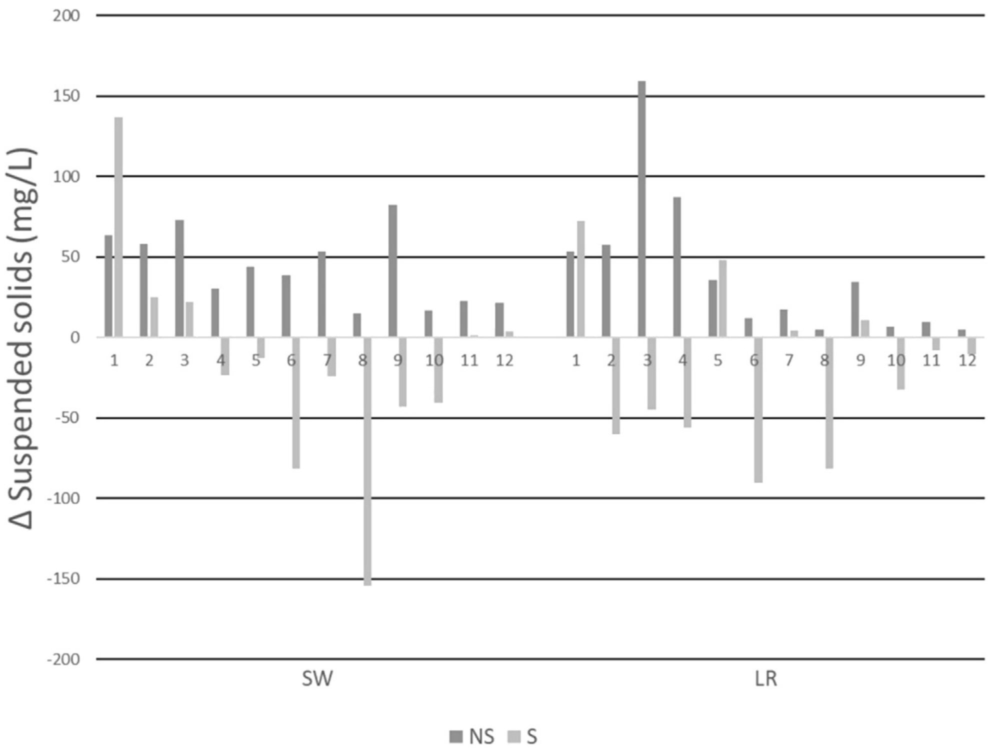

Fig. 3. Balance of SS between output water and input water.

4. Conclusions

The environmental concern due to high oxygen demand in waters should be taken into account when using these wastes, especially sewage sludge, because of the possible consequent risk for natural waters, not only pollution substances but also oxygen demand of waters too. The LR, inorganic and close to be considered as an inert residue, seems adequate to be used in filtration systems, unless for duration of this experiment (twelve weeks). A positive effect on the oxygen demand has been observed (controlling BOD_5) but long-term experiments may be done to determine the effects.

The transformation to the limestone residue into a biological activity media, acting close to the soil, may be the expected process as visual observation of the columns at the end of the experiment evidence. This can open a new perspective of creating "soils or green filters" by using this inorganic material as filtration systems and after the time, the accumulation of organic matter can help to use them as growing media or apply in soil restoration and land recovery.

This research may be considered when designing filters containing these materials, separately or together, forming water filtration systems. Moreover, the use of different types of waters is another important factor as in our results, there were differences between S and NS, including differences in the SS.

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