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# Evaluation of Effectiveness of Domestic Wastewater Treatment by Infiltration Through Sand and Pozzolana in PVC Columns

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**ABSTRACT:**The purpose of this work was to test the efficiency of the treatment of wastewater by infiltration under laboratory conditions, to remove bacterial and organic load and to convert it to available nutrient for crop plants. In order to achieve this objective, polyvinyl chloride (PVC) columns of 133 cm of height were used. The columns were filled with sand and/or pozzolana and loaded with municipal wastewaters. Various parameters were measured at the inlet and outlet of these columns: chemical oxygen demand (COD), biochemical oxygen demand (BOD), ammonium ($NH_4^+$), nitrate ($NO_3^-$), Total Kjeldahl Nitrogen (TKN), total phosphorus (pt), pH and Escherichia coli (E. coli). With an average charge in chemical oxygen demand (COD) of 601.5 mg/L $O_2$ at the input, A better reduction by sand (**S**) followed by mixing sand-pozzolana (**SP**) and finally by pozzolana (**P**) were observed. Good bacterial removal was also achieved with **S**. Indeed, after 49 days of experiment, the output effluent treated by **S** showed only $2.4\times10^4$ CFU/100 mL of Escherichia coli, against $10^8$ CFU/100 mL in the output effluent treated by **P**. Moreover the almost total conversions of the nitrogen to nitrate makes the water treated by sand filter suitable for irrigation, because it is rich in nutrients and enables the conservation of conventional water stocks thereby protecting human life and environmental quality.

**Key word:** Djibouti, Escherichia coli, infiltration, nutrient, wastewater

## INTRODUCTION

With increasing water needs and diversity of sector of activity (agricultural, industrial and drinking water), many countries in the world and particularly in the arid climate countries are forced to use untreated wastewater for crop irrigation. According to Scott *et al.* (2004), 10 % of untreated wastewater is used for irrigation in the world. In the developing countries, farmers with limited means use this water because they are less expensive than conventional water (Keraita & Drechsel, 2004). The domestic effluent could be used as a good source of macro-and micronutrients for agriculture to improve crop yield (Al-Nakshabandi *et al.*, 1997; Papadopoulos *et al.*, 2009). However, agricultural reuse of this water has a great health risk (proliferation and transmission of waterborne diseases) and environmental risk (degradation of soil quality). Hence, this practice leads to a soil contamination with high bacterial loads, heavy metals (HMs) and/or some organic pollutants usually contained in the untreated wastewater (Al-Nakshabandi *et al.*, 1997; Ensink *et al.*, 2002; Kalavrouziotis *et al.*, 2008). In Djibouti, a country in East Africa, which is characterized by an arid climate and low rainfall (200 mm) (Muller, 1982), half of the wells recorded a salt concentration of up to 1200 mg/L due to overexploitation of groundwater (Jalludin & Razack, 2004). On the other hand, according to the National Water and Sanitation Office of Djibouti (ONEAD), in the city of Djibouti, economic and political capital of the country, public sanitation covers only 20% (while the other 80% are supposed to use septic tanks). Farmers use untreated wastewater for irrigation of forage and food crops despite the recommendations of the World Health Organization (WHO). Durable and sustainable use of water for irrigation goes through effective treatment. Several studies (Shuval, 1990; Klutse & Baleux 1995; Faby &

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Brissaud, 1997) show that technique of intensive treatment (trickling filters, activated sludge, etc...) ensure proper elimination of pollution especially in the microbial load. However, this technique is not suitable for developing countries, considering their socio-economic conditions, because it consumes large quantities of energy and requires constant maintenance. Infiltration percolation tested in this work, is a process of aerobic treatment which consists to infiltrate primary effluent decanted or secondary effluent through several meters of sand (Schmitt, 1989). As the wastewater characterization of Djibouti has shown that the concentration of trace metals in the waters is low and is below the standard of FAO (Table 1), we focused our work both on the bacterial load and the nutrient contents.

**Table 1. Trace metal concentrations and *FAO specification (2003)**

| Mg/L | Cr | Cu | Ni | Zn |
|---|---|---|---|---|
| Wastewater | <0.020 | <0.020 | <0.020 | 0.0527±0.003 |
| * | 1 | 5 | 2 | 10 |

The objective of this study was to evaluate the effectiveness of domestic wastewater treatments by granular materials (sand and pozzolana), which are available and cheap in Djibouti, and to compare the performance of sand and pozzolana filters in removal of microorganisms and organic matter, and conversion to nutrients which have the positive impact on crop productivity.

## MATERIALS & METHODS

Wastewater, collected at the exit of the decanter of the municipal treatment plant of Besancon (France), was treated by the technique of percolation-infiltration. We used the terms: input effluent for the wastewater from the treatment plant after decantation; output effluent for the water treated by our columns; S for sand of effective grain size between $0.25 < d_{10} < 0.45$ mm as recommended by Liénard (2001); P for pozzolana of size between $6 < d_{10} < 10$ mm and SP for equal proportion of sand on top of pozzolana. The pilot as shown in Fig 1 is composed of a set of 15 columns. The polyvinyl chloride (PVC) columns have an inside diameter of 12.5 cm and a height of 133 cm. The alimentation (10 cm/day) was alternating 3 days feeding (Monday, Wednesday, and Friday) and rest periods allowed to avoid filter clogging**.** The columns are equipped with lateral pipes of 0.6 cm of diameter for oxygenation and filled on a depth of 20 cm of big gravel (1 cm diameter) at the bottom and 90 cm of sand and/or pozzolana. Over the 7 weeks of the experiment, input and output effluent from the treatment plant were characterized for nutrients ($NH_4^+$, $NO_3^-$, Total Kjeldahl Nitrogen [TKN] and total phosphorus), pH, and indicator organism (Escherichia coli). All chemical analyzes were performed in the Laboratory of Water Chemistry of Besancon and microbiological parameters were tested by the Laboratory of the Hospital of Besancon. All these analyzes were conducted according to standards methods. These laboratories are accredited according to the ISO 17025 norm. Input and output effluent samples were analyzed for pH using a pH meter NF T 90 008. Chemical Oxygen Demand (COD) was determined by colorimetric method using potassium dichromate ISO 6060:1989. Biochemical Oxygen Demand ($BOD_7$) was measured by the dilution and seeding method with allylthiourea addition according to ISO 5815-2:2003. $BOD_7$ was shown over $BOD_5$ for timing reason for laboratory since sampling was done on Monday and analysis on the next Monday. The total phosphorous was determined by inductively coupled plasma mass spectrometry according to standard methods ISO 118885, Ammonia content was determined by colorimetric method NFT 90-015-1, TKN by EN 25663 and nitrate content by Ionic Chromatography according to the standard method ISO 10304-1. Escherichia coli concentration was determined by using a standard method ISO 9308-1 and total floral by ISO 6222:1999. The removal efficiency (%) of S, SP and P were calculated, using the following equations:

$$\text{Removal efficiency (\%)} = \frac{C0 - C1}{C0} * 100$$

were C0 and C1 are the starting and final concentrations of ion (mg/L).

The analytical data collected was processed statistically applying Tukey's HSD test, using the statistical package SPSS Ver.20.

## RESULTS & DISCUSSIONS

The input effluent pH was between 7.4 and 7.66. It was characteristic of the municipal wastewater (El Halouani *et al*., 1993). pH of the output effluent treated by **S**, **SP** and **P** were in the range of 7.66-8.07, 7.75-7.89 and 7.62-8.13 respectively (Table 2). They were moderately alkaline, but remained within the recommended range for irrigation water (6.5 to 8.4) according to the FAO guidelines (Pescod, 1992).

The performance of columns was evaluated by estimation of the total flora concentration and in terms of E. coli removal. The input effluent average concentration of total flora was about $2.38\times10^9$ CFU/ 100 mL. The reduction of this flora was interesting because from the first week, flora abatement was above 99% for all treatments (**S**, **SP** and **P**). A slight predominance was noticed for the **S** and **SP**.

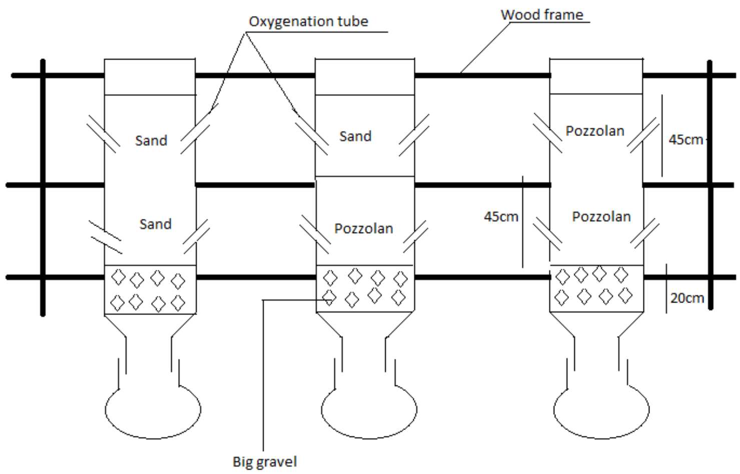



**Fig. 1. Diagram of the columns**

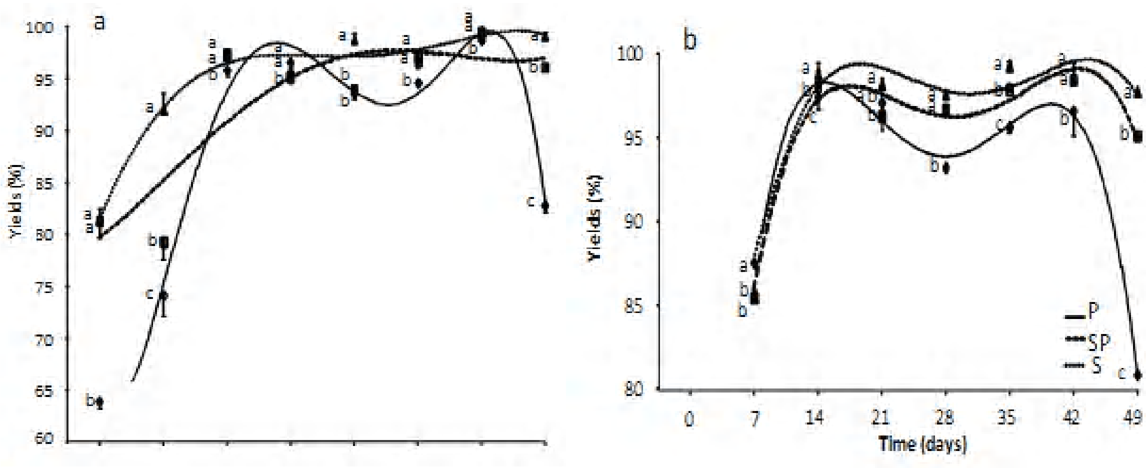
Escherichia coli enumeration was monitored from the 35th day. The input load averaged at $3.54\times10^7$ CFU/ 100 mL. After 49 days of experiment, there were, in the output effluent treated by **S**, only $2.4\times10^3$ CFU/100 mL of E. coli corresponding to an abatement of 99.99% while there was $1.75\times10^7$ CFU/100 mL of E.coli in the output effluent treated by **P** (Table 2). According to several authors (Sharma *et al*,. 1985; Bomo *et al.*, 2003), the elimination of bacteria is controlled by filtration and adsorption. These mechanisms depend on grain size, clogging of filter, pH, and bacterial concentration. The better elimination of bacteria by **S** compared to **P** can be explained by their difference of accessible surface. **S** and **P** have both high specific surfaces. However in the case of **P**, most of this surface is inside micro and macro pores and is therefore mostly not accessible to a fast flow of water. The surface available for bacteria to be adsorbed is thus less than with **S**. Microbiological removal obtained with **S** was interesting because, results were in the range of reduction (1-3 $\log_{10}$) obtained by Potts *et al.* (2004) in the lysimeter sand. The WHO (1989) standard recommended for the reuse of treated wastewater for irrigation of cooked crops (Coli.F $<10^4$ CFU/100 mL) was reached.

During the experiment, the output effluent COD was unstable partly because of input effluent fluctuation. So results were presented as percentage of abatement. The input effluent COD recorded a range of 172. 14 to 1042.34 mg/L $O_2$ with an average value of 601.48 mg/L $O_2$. It can be observed in Fig. 2a, that after one week of operation, 90% of this load was cut down by the **S** treatment and remained above this value during the rest of the experiment. In order to achieve this performance, **SP** mixture treatment required an additional week of operation. Performance with **P** was unstable throughout the experiment. Subsequently, the removal efficiency of COD of columns **S** continued to improve until reaching 99.58% while at the same time, the elimination of COD by **SP** was varying, and remained above 90%. The removal efficiency of **P** remained low. Broussard (1985) related poor pozzolana result to preferential pathways created by water. Statistical analysis of the weekly abatement result by the SPSS software with tukey test showed that **S** and **SP** abatement were not significantly different and that they differed significantly from those of **P** Elimination of COD which was mainly due to sedimentation and particular filtration phenomena. The **S** treatment led to the most important abatement. Thus, our results were consistent with those of Pell and Nyberg (1989), who obtained 91% of the reduction after 7 days of column operation. From the 2nd week the output COD value for all treatment was below 60 mg/L $O_2$, which was the guide value of the French decree of August 31, 2010 of form COD of treated wastewater for irrigation of crops to be eaten raw. However, for the **P** columns, the abatement was more unstable and collapsed at the 7th week.

Fig. 2b below shows the change in the reduction of $BOD_7$ during the period of the experiment. The filter pilot treatment led to the important abatement in $BOD_7$ after only 2 weeks of operation. All treatment reached abatement above 95%, for an average value of 185.48 mg/L $O_2$ at the input. The $BOD_7$ concentration of output effluent was in the range of 1.42±0.24 – 7.15±0.86 mg/L $O_2$ by **S** and 3.18±0.69 – 7.59±0.3 mg/L $O_2$ by **SP** treatment. The $BOD_7$ removal by **P** treatment fluctuated but still averaged over 90%. From the results presented above it can be concluded that the aerobic reactor columns have great potential in biodegrading organic pollutants present in municipal wastewater.

**Table2. Evolution of the pH, removal of total floral (%) and Escherichia coli (CFU/100 mL) during the experiment (n=5)**

| | days | 0 | | 7 | | 14 | | 21 | | 28 | | 35 | | 42 | | 49 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | unit | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| **pH** | | | | | | | | | | | | | | | | | |
| P | | 7.62 | 0.05 | 7.76 | 0.14 | 7.89 | 0.39 | 8.04 | 0.35 | 7.91 | 0.36 | 8.13 | 0.36 | 8.02 | 0.29 | 7.79 | 0.30 |
| SP | | 7.89 | 0.03 | 7.87 | 0.04 | 7.76 | 0.13 | 7.78 | 0.04 | 7.87 | 0.04 | 7.75 | 0.07 | 7.89 | 0.04 | 7.83 | 0.07 |
| S | | 8.07 | 0.04 | 7.68 | 0.08 | 7.81 | 0.04 | 7.79 | 0.04 | 7.75 | 0.06 | 7.66 | 0.05 | 7.95 | 0.04 | 7.78 | 0.08 |
| **Removal of total floral** | **%** | | | | | | | | | | | | | | | | |
| P | | - | | 99.27 | 0.04 | 99.61 | 0.05 | 99.62 | 0.06 | 99.44 | 0.05 | 99.41 | 0.03 | 99.56 | 0.02 | 99.86 | 0.01 |
| SP | | - | | 99.44 | 0.08 | 99.85 | 0.01 | 99.78 | 0.02 | 99.91 | 0.02 | 99.83 | 0.01 | 99.92 | 0.03 | 99.92 | 0.03 |
| S | | - | | 99.52 | 0.05 | 99.86 | 0.01 | 99.95 | 0.01 | 99.92 | 0.01 | 99.89 | 0.00 | 99.95 | 0.02 | 99.95 | 0.03 |
| **Escherichia.coli** | **CFU/100 mL** | | | | | | | | | | | | | | | | |
| P | | - | | - | | - | | - | | - | | $4.03\times10^{6}$ | 0.04 | $9.82\times10^{6}$ | 0.03 | $2.4\times10^{7}$ | 0.03 |
| SP | | - | | - | | - | | - | | - | | $4.7\times10^{5}$ | 0.02 | $2.59\times10^{5}$ | 0.01 | $2.05\times10^{5}$ | 0.02 |
| S | | - | | - | | - | | - | | - | | $1.34\times10^{4}$ | 0.01 | $1.01\times10^{4}$ | 0.01 | $2.4\times10^{3}$ | 0.02 |



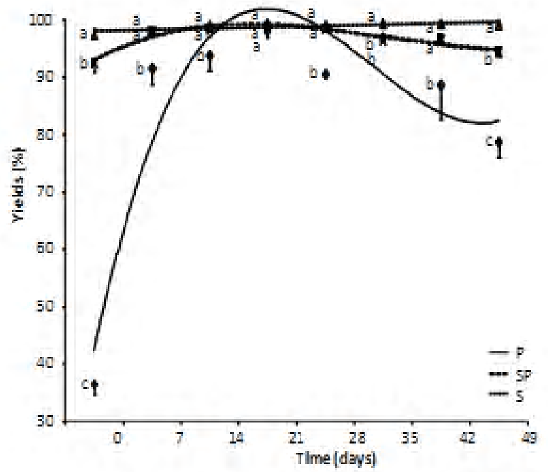

**Figs. 2. Chemical Oxygen Demand (graph a) and Biochemical Oxygen Demand$_{(7)}$ (graph b) yields according to the time. ▲= Effluent treated by S. ■ = Effluent treated by PS. ◆= Effluent treated by P. The points are means of Chemical Oxygen Demand and Biochemical Oxygen Demand$_{(7)}$ yields. Vertical bars indicate standard deviation (±) (n=5). For the sake of clarity, only the halves of the interval bars have been represented. Different letters, for the same date, over points indicate significant differences according to Tukey test at p<0.05**.

The input effluent concentration of phosphorus ranged between 2.22 - 9.71 mg/L. The total phosphorus removal by **S** and **SP** was important from the first week and to above stable 90% of during the remainder of the experiment. The output effluent phosphorus concentration ranged between 0.02 - 0.15 mg/L and 0.03 – 0.45 mg/L for **S** and **SP** treatment respectively (Fig 3). The elimination with P treatment reached the maximum yield after 21st day of the experiment (90.98%) and slowly decreased. After one week of operation, its concentration ranged between 0.19±0.07 to 1.37±0.18 mg/L. Decrease of phosphorus elimination by **P**, from 35 days, suggested the possible saturation of filter media and decreasing sorption capacity. Low abatement was interesting because phosphorus has a positive impact on crop productivity. Phosphorus retention was due to sorption and precipitation phenomena (Faulkner & Richardson, 1989; Vymazal *et al.*, 2000). These reactions depended on the Ca, Fe and Al contents of the filter (Korkusuz *et al.*, 2005).

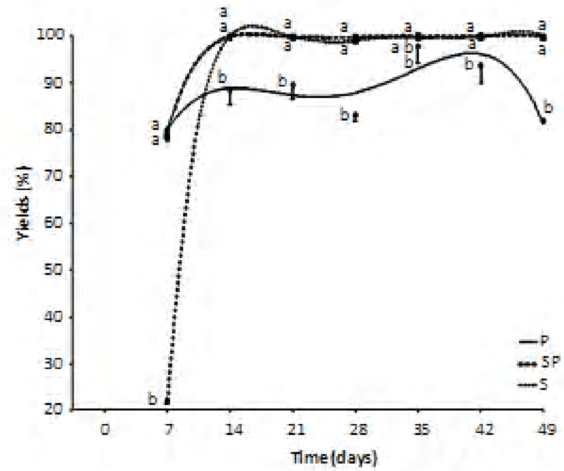
Fig. 4 showed the change in ammonia removal during the experiment. The average ammonia removal for **S** and **SP** was 99.61% and 99.79% respectively and the corresponding output effluent ammonia concentration was between <0.05-0.22±0.05 mg/L and <0.05-0.09±0.03 mg/L respectively for **S** and **SP** treatment, from the second week. The average ammonia removal for **P** was 82.41% and the corresponding output effluent ammonia concentration was between 1.0±0.52-6.54±1.16 mg/L, for the same period. Ammonia elimination can be explained by its transformation into volatile ammoniac ($NH_3$) or by adsorption on organic matter and further biological conversion to nitrate. According to Hammer and Knight (1994) this volatilization occurred when pH of input effluent range between 7.8-8.4. As pH of our input effluent varies from 7.44-7.66, this mechanism was limited. In our case absolutely no ammoniac smell was detected.

Fig 5a showed the changes in TKN removal during the experiment. **S** treatment showed a good performance in terms of TKN removal. The average TKN removal for **S** and **SP** was 97.7% and 94.93% respectively and the corresponding output effluent TKN concentration was between 0.52±0.07-1.85±0.07 mg/L and 0.8±0.41-2.97±0.31 mg/L respectively for S and SP, from the second week. The average TKN removal for **P** was 80.14% and the corresponding output effluent TKN concentration was between 4.56±0.52-13.5±2.42 mg/L, for the same period, for average output effluent TKN concentration. The reduction of organic nitrogen suggested an intense mineralization.

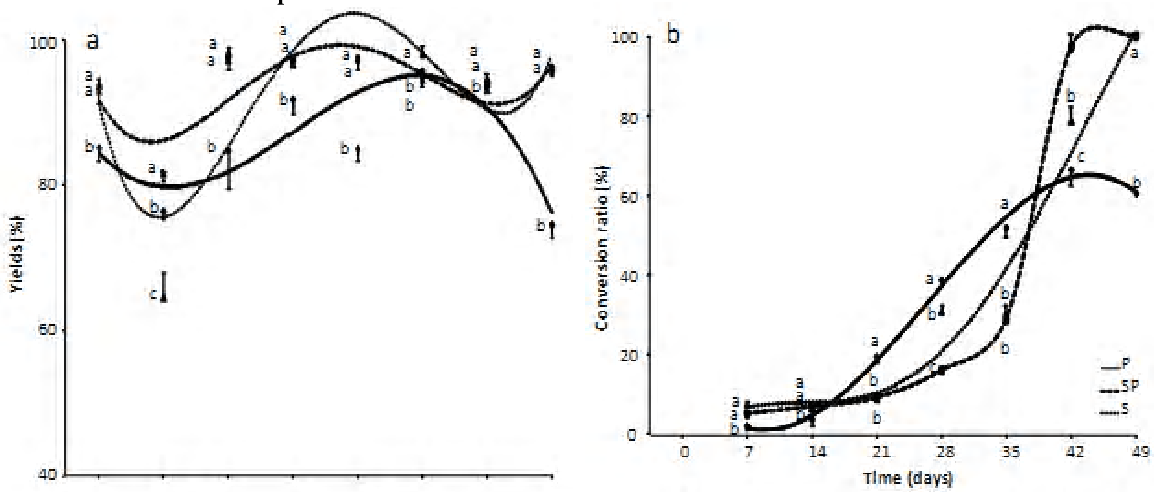
Fig 5b below showed the change of the conversion ratio of nitrogen during the experiment. The conversion ratio of nitrogen was calculated as the ratio of nitrate output on NTK input. This ratio reached 100% after 49 days for **S** and **SP** treatment, whereas it was 60% with **P**. TKN was mainly transformed into nitrate, a more assimilate nitrogen form for plants. The output effluent nitrate concentration rose from 6.12±2.35 to 229.97±36.49 mg/L and from 4.4±0.65 to 235.88±7.59 mg/L respectively for **S** and **SP**. The output effluent nitrate concentration for **P** rose from 1.8±0.5 to 127.57±23.71 mg/L. The average inlet nitrate concentration was 2.78 mg/L.




**Figs. 3. Total phosphorus according to the time. ▲= Effluent treated by S. ■ = Effluent treated by PS. ◆= Effluent treated by P. The points are means of total phosphorus. Vertical bars indicate standard deviation (±) (n=5). For the sake of clarity, only the halves of the interval bars have been represented. Different letters, for the same date, over points indicate significant differences according to Tukey test at p<0.05**




**Figs. 4. Ammonia yields according to the time. ▲= Effluent treated by S. ■ = Effluent treated by PS. ◆= Effluent treated by P. The points are means of Ammonia yields. Vertical bars indicate standard deviation (±) (n=5). For the sake of clarity, only the halves of the interval bars have been represented. Different letters, for the same date, over points indicate significant difference according to Tukey test at p<0.05**




**Figs. 5. Total Kjeldahl Nitrogen (graph a) and conversion ratio of nitrogen (graph b) according to the time. ▲= Effluent treated by S. ■ = Effluent treated by PS. ◆= Effluent treated by P. The points are means of Total Kjeldahl Nitrogen yields and conversion ratio of nitrogen. Vertical bars indicate standard deviation (±) (n=5). For the sake of clarity, only the halves of the interval bars have been represented. Different letters, for the same date, over points indicate significant differences according to Tukey test at p<0.05**

For Rousselle (1990), nitrogen was present in wastewater in two main organic forms (proteins, amino acids) and mineral ($NH_4^+$, $NO_3^-$). The organic form will therefore undergo ammonification followed by nitrification. According to Ouazzani *et al.* (1996) ammonium ions were largely eliminated by absorption onto the sand particles and organic particles, before undergoing nitrification if the conditions of aeration allow them. Nitrification was the biological phenomenon of oxidation of ammonia to nitrate by autotrophic microorganisms (Pochon *et al.*, 1958). The bacterium responsible of this reaction was Nitrosomas (Pochon & De Barjac, 1958; Dommergues & Mangenot, 1970). Nitrification was influenced by temperature and pH. The optimum area of the porous medium of pH for nitrification was ranged between 6.6 and 9. The Fig 5b also showed that the organic nitrogen did not appeared significantly as mineral nitrogen in the outlet effluent until the 6th week. Although, it is possible that a total conversion to $N_2$ occurred, it is mostly probable that the mineralized nitrogen was used in the column for the creation of the biofilm. After 5 weeks a stable state is reached and nitrates are liberated.

## CONCLUSION

The treatment performance depended on the types of filters. Pozzolana took a longer time to set, showed unstable efficiency and a performance drop after the 6th week probably due to clogging. While a good level of treatment was achieved with the sand after only one week of experiment. Sand provided good removal of microorganisms and a good conversion of organic nitrogen into mineral nitrogen easily assimilated by crop plants. Sand infiltration promoted a healthy development of the biofilm that degrade organic matter. However, biomass growth, accumulation of suspended solids should be monitored to prevent clogging. This monitoring could be achieved by COD measurement. Sand and mixture sand-pozzolana presented similar results. This suggests that the abatement took place in the part of the columns. Sand treatment allowed elimination of pathogen bacteria while preserving the wastewater nutritional quality. The use of treated wastewater will lead to reducing the cost of fertilizer and conservation of freshwater resource. Considering this result, the sand was retained for further experiments the field in Djibouti.

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