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Physico-Chemical Quality Study of Soils Irrigated with Treated Domestic Wastewaters

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Abstract

In Burkina Faso, a semi-arid country, the reuse of wastewaters for irrigation delivers water and nutrients in abundance obtained free of charge at any time of the year, especially in the areas of dry farming and arboriculture. But these wastewaters are very loaded with suspended and dissolved substances and may clog the soil and cause a decrease in porosity. It is therefore necessary to know the various elements contained in these waters in order to monitor their progress in the soil. Our objective in this study is to determine the impact of wastewaters on soil. For this, we directly used the untreated surface water from the dam of Loumbila and domestic wastewaters treated by microphytes lagooning at the Station of Processing and Purification of the International Institute for Water and Environmental Engineering (2iE) to irrigate the soil. Lettuce culture is experimented. For each type of water, a plot in which lettuce is grown is irrigated with this water and there also is a control plot irrigated with the same water but not containing growing lettuce. Throughout the duration of the study, the physical and chemical parameters of these soils were measured. The results show that soil properties were not significantly affected by irrigation with treated wastewaters, except for the sodium content which is higher in irrigated soils. Similarly, the study shows that the treated wastewaters contain enough materials to make a rich soil.

Keywords: Semi-arid country, arboriculture, water, microphytes lagooning, chemical parameters.

Introduction

In arid and semi-arid regions, water scarcity is a serious handicap to increasing food production. In addition, population growth, urban development, the evolution of personal hygiene and industrial expansion are behind the growth in demand for water of good quality. Consequently, there has been an increase in the volume of water discharged after use which contains constituents valued in agriculture especially in arid and semi-arid areas where the reuse of this water for irrigation is increasing. The reuse of wastewaters, despite its proscription in several regions of the world, is due in part to the fact that these waters have the dual advantage of providing irrigation water that contains nutrients in abundance and which is obtained at no cost at any period of the year[1,2,3] Reused especially in the fields of dry farming and arboriculture these wastewaters contribute to improving incomes, the nutritional status of populations, a significant part of global crops and the preservation of the environment[4-6].

In addition, the continuity of the availability of supply of wastewaters is ensured with the increasing urbanization of cities which reject about 70% of their water consumption after use[7,8]. This availability of the resource, in addition to its other benefits, explains the persistence of farmers to the use of this type of water. These reasons also explain the observed rise in the use of these waters, despite the risks caused by their use on human health due to their content of traces of pathogenic elements, and their high nitrogen content[9]. However, the use of wastewaters for irrigation can be a source of pollution of soil, because these waters highly charged with substances may clog the soil and cause a decrease in porosity. Several waterborne diseases are caused by these types of waters.

Therefore, it is necessary to know the various elements contained in the wastewaters in order to follow their evolution in the soil[10,11,12]. This is the aim of the present study which seeks to determine the impact of wastewaters on soils[13].

Material and Methods

Site of study: The present study was conducted on the wastewater treatment plant of the International Institute of Water and Environmental Engineering (2iE) and concerned relevant agronomic trials. Lettuce culture was conducted. The experimental setup is shown in figure-1 in annex.

The irrigation is performed twice a day (morning and evening) with watering cans of 10 liters capacity.

Instruments and methods: Methods of analysis of the waters used for irrigation: The waters are analyzed in the laboratory for wastewater and drinking water from 2iE. Several parameters are analyzed and concerned the pH and the electrical conductivity.

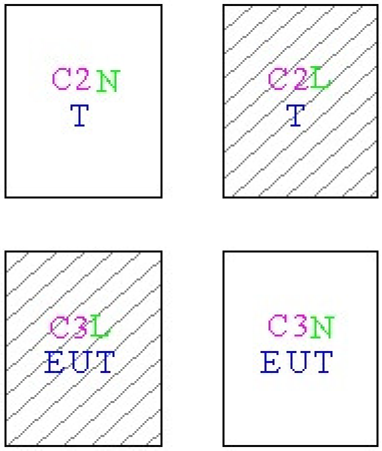

Figure-1
Experimental plots used

T: water from the dam of Loumbila, EUT: treated domestic wastewater, C2N (T): neutral plot irrigated with water from the dam of Loumbila (no culture of lettuce), C3N (EUT): neutral plot irrigated with treated domestic wastewater (no culture of lettuce), C2L (T): plot irrigated with water from the dam of Loumbila where lettuce is cultivated, C3L (EUT): plot irrigated with treated domestic wastewaters where lettuce is cultivated.

Determination of the pH: The pH of the water is measured with a pH-meter which gives a direct reading of the pH value. The pH is measured on a daily basis and makes it possible to monitor the acidity and basicity of the water. This allows one to check if the pH of the irrigation waters influences that of the soils or not.

Determination of the electrical conductivity: The electrical conductivity of water gives a good approximation of its salinity[14,15]. It is measured by using a conductivity meter equipped with a cell for measuring the conductivity, a system for adjusting the measuring range and a device for automatically correcting the temperature. This ensures an accuracy of 1 mS/cm at a temperature of 20°C.

Determination of the content in nitrogen (N), phosphorus (P) and potassium (K): The analysis of nitrates and phosphates is based on the principle of a colorimetric assay of NO_3^- and PO_4^{3-} ions in the presence of their respective reagent. The material used for their measurement consists of a DATALOGGING labtop spectrophotometer also called HACH DR 2010, which is an absorption spectrometer whose wavelengths are set for each type of ion. In addition to the determination of nitrate ion content, that of nitrogen in ammonia is made to estimate the total assimilable nitrogen content in the water. This assessment is based on the principle of distillation of the sample followed by a titration with sulfuric acid 0.02 N. The equipment used to perform these operations is a manual distiller Bioblock 10929, a 100ml dispenser and all the necessary laboratory glassware for the completion of this work.

The analysis of potassium is by emission spectrometry with a flame obtained by the combustion of butane in air as the excitation source. The equipment used is a flame emission spectrophotometer.

References to these last two analyzes are the norm NF T90-015 for the determination of the ammonium ions and procedure M03013 24/03/2000 of the 2iE laboratory for potassium. The method used for the determination of potassium is the same as that used for determining sodium in water.

Determination of the content in calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}), bicarbonate ions (HCO_3^-) and carbonate ions (CO_3^{2-}): Measurement of the HCO_3^- and CO_3^{2-} ions in water is a simple acid-base titration. These are rapid assays in which the presence of these ions is determined by using acid-base indicators. The material used is laboratory glassware. This is a manipulation that is performed once a month in order to follow the evolution of the content of these ions in the water. The determination of calcium and magnesium is by complex formation of these ions by EDTA in highly basic medium.

Determination of the chemical oxygen demand (COD) of the waters: The chemical oxygen demand (COD) is the amount of oxygen required to oxidize organic substances in the water in well defined operating conditions. It allows one to monitor the pollution load of wastewaters[16]. The oxidant used here is potassium dichromate, and the reaction is carried out by heating and refluxing in highly acidified medium to have severe oxidation conditions. It follows that a major part of oxidizable substances dissolved in water are consumed by the reaction. COD is measured with the HACH DR2010 absorption spectrometer in the range of wavelengths from 420 to 600nm.

Determination of the biochemical oxygen demand in 5 days (BOD_5): The phenomena of self-purification in surface waters results from the degradation of organic pollutant loads by micro-organisms. The activity of the latter tends to consume oxygen and it is this decrease in oxygen in 5 days in the medium which is measured by BOD_5. Indeed, at 20 ° C the degradation of organic matter begins immediately. BOD_5 is expressed in mg of oxygen consumed per liter of water during five days at 20°C.

Determination of total suspended solids (TSS) in the waters of irrigation: The analysis of total suspended solids (TSS) provides the amount of substances not dissolved, whether organic or inorganic. It is done as follows: 100 ml of water are filtered with membrane filters previously weighed before filtration. After filtration, they are dried in an oven at 115°C, and then weighed again. The amount of suspended solids is obtained by the following calculation

$$\frac{\text{(mass of dried membrane after filtration)} - \text{(mass of membrane before filtration)}}{\text{Volume of filtered water (100 ml)}}$$

The amount of suspended matter is expressed in mg / l of water.

Determination of the physicochemical properties of the soils:
Physical properties of surface of the soils: The measurement of the physical properties of the surface of the soils was performed by tests on the field. The monitored parameter is the infiltration capacity. It was determined by the method of the double ring with the infiltration meter of Müntz shown in figure-2.

Figure-2
Infiltration meter of Müntz

The inner cylinder had a diameter of 25 cm and the outer cylinder 33 cm in diameter. The tests were carried out by imposing a constant load (3cm) in the central cylinder. The presence of the outer cylinder is used to limit the lateral diffusion of water. The infiltration process shown in figure-3 generally begins with a rapid decrease and then decreases more slowly to reach a steady state.

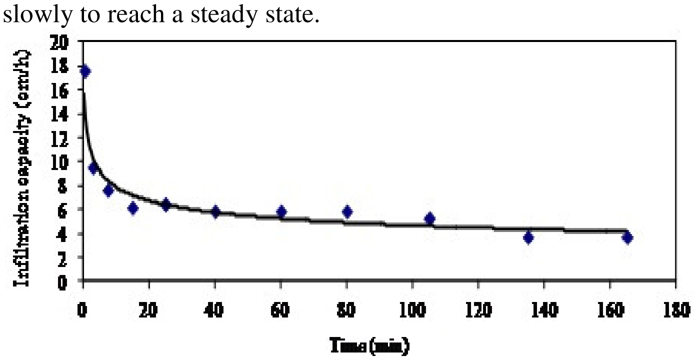

Figure-3
Determination of the infiltration capacity with the infiltration meter of Müntz

Granulometric analysis: Each experimental plot was the subject of a statement of soil profile. The approach adopted was to make holes in the auger on all four measuring plots. A total of thirty (30) samples were collected on the four experimental plots. The samples collected were described visually before being analyzed at the "Laboratory of Agronomy of the University of Niamey" in Niger by the method of Robinson pipette. The textural triangle used is the French Soils Repository in figure-4 in annex[17].

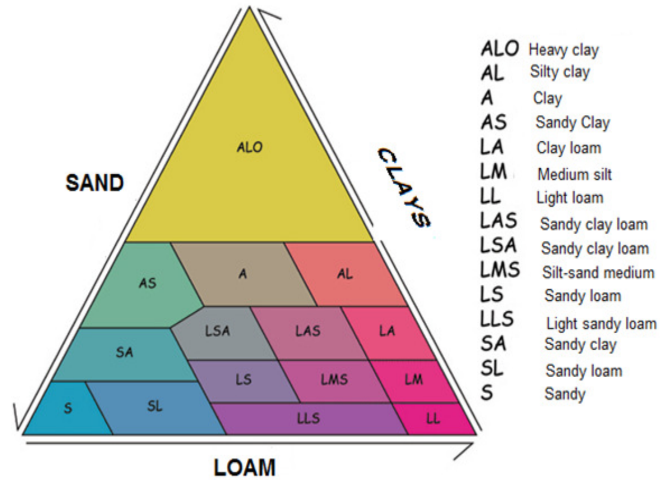

Figure-4
Repository soils textural triangle involving french percentages of clay (< 2 µm), silt (2 to 5 µm) and sand (50 to 2000 µm)

The electrical conductivity and the pH of the soils: Soil samples were collected using an auger to a depth of 20 cm. The measurement of the conductivity of the soil is often used to measure the salinity of the soil paste. It was done according to international standard ISO 112565 (1994). Soil samples were air-dried, sifted, weighed and used to make solutions by adding distilled water which mass is equivalent to five times the mass of soil. The conductivity of the filtrate is then measured. The conductivity meter used is the same as that used for measuring the conductivity of the waters. The conductivity of the distilled water used to make the soil solution should not exceed 0.2 mS/cm at 25°C (water quality 2 according to ISO 3696).

The pH of the soils also provides a measure of the salinity of the soil paste. Soil samples were prepared in the same manner as in the case of the electrical conductivity measurement. However the soil solution needs not be filtered and the pH is measured directly in the soil suspension. Two types of solutions were used: i. one is obtained by dissolving the soil paste in distilled water which conductivity must not exceed 0.2 mS/cm and the pH not higher than 5.6; ii. the other is made by dissolving the soil paste in a potassium chloride solution (1 mol / l).

All these measurements were performed in the laboratory of 2iE.

Determination of chemical parameters of the soils: Soil samples were analyzed at the laboratory of "National Bureau of Soils (BUNASOLS)" of Burkina Faso to determine the content of various chemical elements.

The following soil chemical parameters were analyzed: nitrate, ammonium and phosphate ions. The methods used are compliant with international standards.

Results and Discussion

Monitoring of physicochemical parameters of the waters: Physicochemical parameters assessment is made after the determination of a certain number of physicochemical parameters characterizing the waters and the soils. We will present and discuss the results of each parameter. Figure-5 to figure-14 in annex show the plots of the data corresponding to the evolution of these parameters with time.

pH of the waters: The curve in figure-5 in annex indicates the evolution of pH of the waters. We find that the pH of the treated wastewaters has values above 7. Therefore they are slightly basic. However, surface waters from the dam of Loumbila are slightly acidic. One can notice that the pH of these waters meet the standards required by the United Nations Food and Agriculture Organization which establishes the range of pH for water of irrigation in the range from 6.5 to 8.5[18].

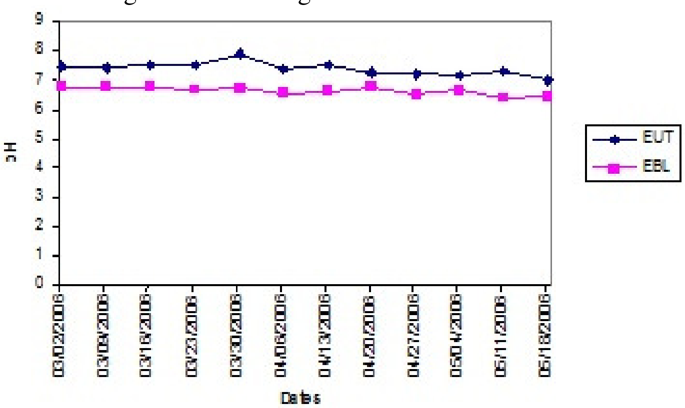

Figure-1
Evolution of the pH of the waters (EUT: treated wastewaters; EBL: raw water from the dam of Loumbila)

Electrical Conductivity of the waters: The curves of figure-6 in annex the change in the conductivity of the waters with time. It was found that the conductivity values of wastewaters are vastly superior to those of surface waters; sewages are therefore much more saline than raw waters.

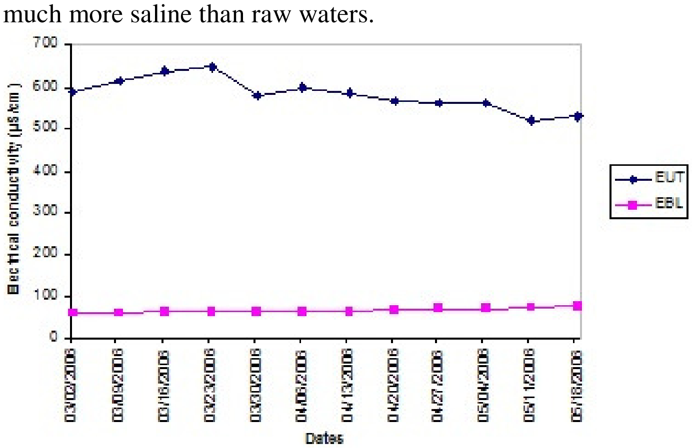

Figure-6
Evolution of the electrical conductivity of the waters

Content in ammonium ions (NH_4^+) and nitrate ions (NO_3^-): Figure-7 and figure-8 in annex show the evolution of these two parameters in both types of waters. We can observe from these curves that wastewaters are richer in nitrogen than surface water from the dam of Loumbila.

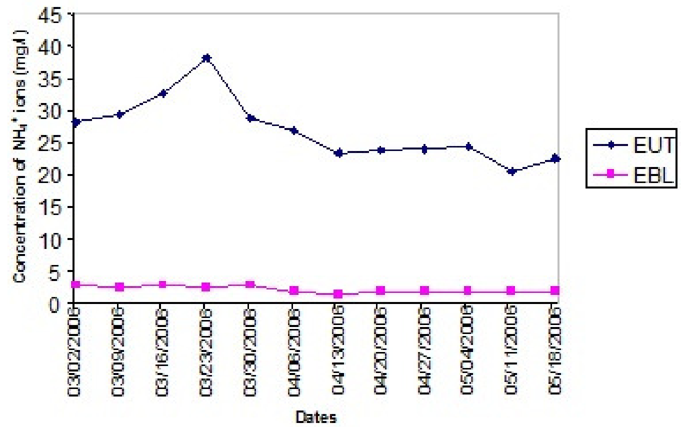

Figure-7
Evolution of the concentration of NH_4^+ in the waters

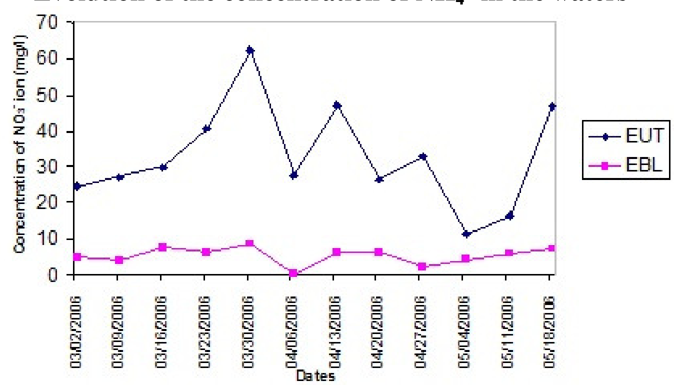

Figure-8
Evolution of the concentration of NO_3^- in the waters

The curves indicate that both types of waters have a much higher concentration of nitrate ions than ammonium ions (NH_4^+): nitrogen is therefore abundant in water in the form of nitrates.

These parameters are critical in the salinity of water. Nitrogen undergoes a lot of changes in the water and when the water is basic, ammonium ions are transformed into ammonia according to the reaction:

$$NH_4^+ + OH^- \longrightarrow NH_3(g) + H_2O$$

When the pH of a soil is high, a nitrification reaction occurs and transforms NH_4^+ or NH_3 into NO_2^- and NO_3^-. This is an oxidation reaction that occurs through enzymatic catalysis by bacteria in soils and water. The nitrite ion is a transitional form that acts as a bridge in the nitrification reaction. The chain reaction is of the following type:

$$NH_4^+ \leftrightarrows NO_2^- \leftrightarrows NO_3^-$$

or: $$2\,NH_4^+ + 2O_2 \rightarrow 2\,NO_2^- + 2\,H_2O + 4\,H^+$$

Ortho phosphates PO_4^{3-} and phosphoric anhydrides P_2O_5: The curves of figure-9 and figure-10 in annex show the evolution of these two parameters in the irrigation waters. The analysis of the curves shows that phosphate ions and the phosphoric anhydrides are in very small quantities in surface waters. Therefore these waters are very low in phosphorus.

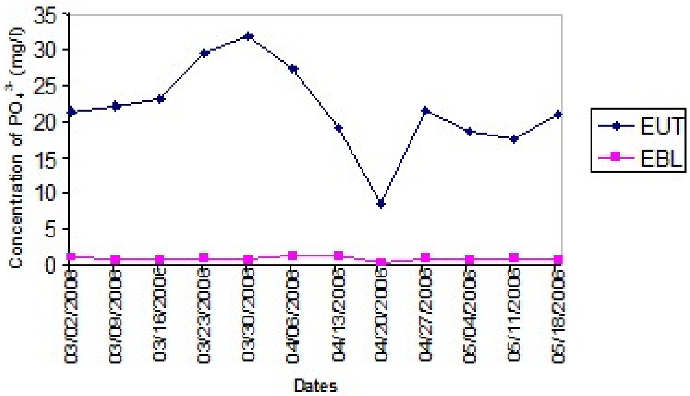

Figure-9
Evolution of the concentration of PO_4^{3-} in the waters

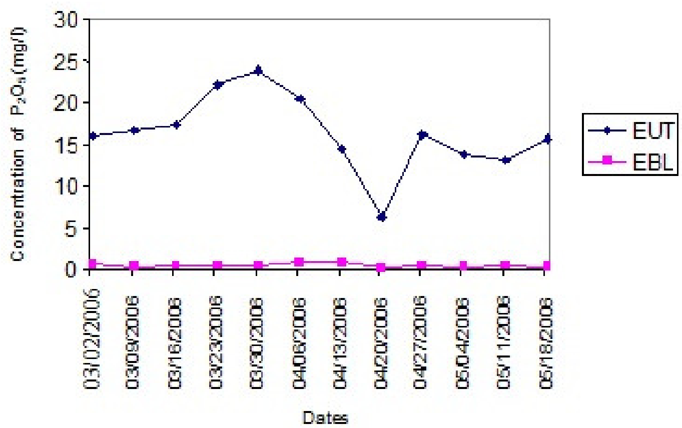

Figure-10
Evolution of the concentration of P_2O_5 in the waters

However, in wastewaters, PO_4^{3-} contents are quite high with an average of 21.88 mg/l. In water, orthophosphates are transformed into phosphoric anhydrides according to the reaction:

$$2\ PO_4^{3-} + 3\ H_2O \rightarrow P_2O_5 + 6\ OH^-$$

Phosphoric anhydride P_2O_5 has an average concentration of 16.35 mg /l. Wastewaters are therefore richer in phosphorus than surface waters.

Potassium K^+ and anhydrous potassium oxide K_2O: The curves of figure-11 and figure-12 in annex show the evolution of these two parameters in the irrigation waters. Potassium ion plays an important role in the salinity of water. Its concentration is high at the beginning of the experiment in the wastewaters. Then we observe a decrease before it undergoes a slight increase to become almost stationary. However in raw waters, the concentration is not high enough but is almost stationary during the period of study. Wastewaters are more saline compared to surface waters.

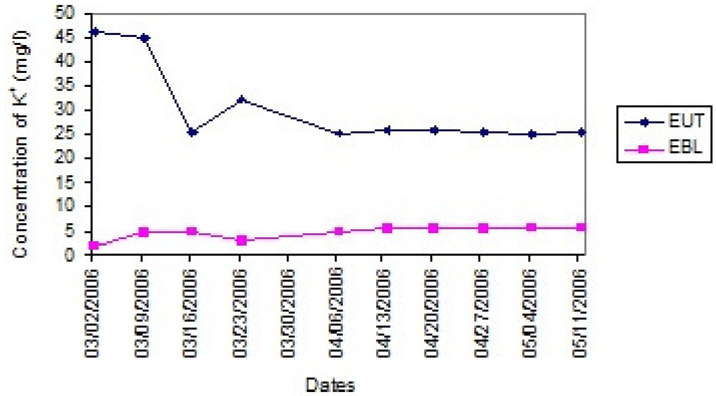

Figure-11
Evolution of the K^+ concentration in the waters

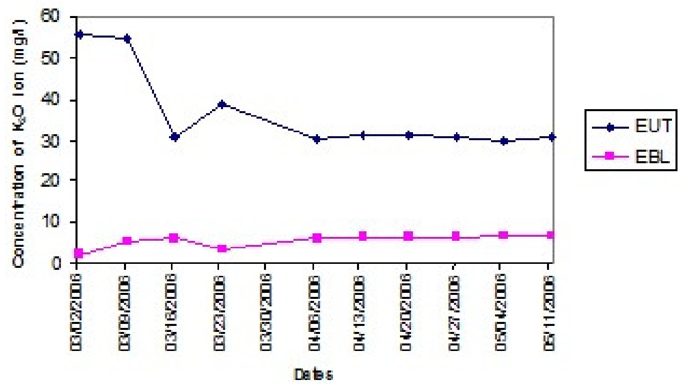

Figure-12
Evolution of the K_2O concentration in the waters

The transformation of potassium ion into potassium oxide is an oxidation reaction which is given by the following reaction:

$$2\ K^+ + 3\ H_2O \rightarrow K_2O + 2\ H_3O^+$$

The concentration of K_2O is deduced from this reaction. Potassium is found in these two forms in waters and passes into the soil by irrigation. Its content in the soil depends on its concentration in the waters. Therefore soils irrigated with wastewaters are richer in potassium than those that use surface waters.

Sodium Na^+: Figure-13 in annex shows the evolution of the sodium concentration in irrigation water over time. Sodium content like that of potassium can be used to monitor the water salinity. The curve indicates that the concentration of sodium in the water from the dam of Loumbila does not virtually change throughout the experimentation period.

The sodium concentration is very high in wastewaters and this can affect the soil permeability and cause a problem for water infiltration. To better understand the evolution of sodium in the waters, we carried out the analysis of magnesium and that of calcium, whose concentrations in water are closely related to that of sodium.

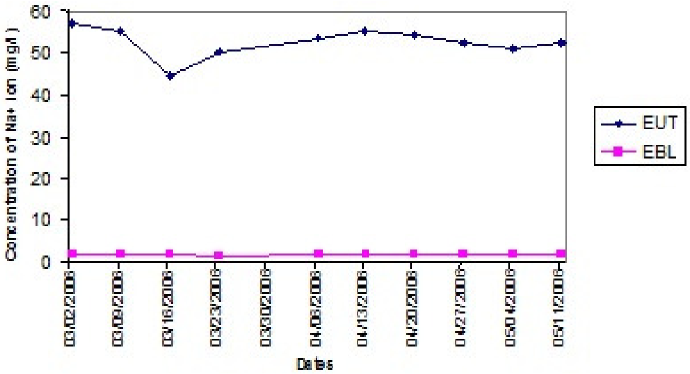

Figure-13
Evolution of the Na^+ concentration in the waters

Data of monthly analyses: These analyses involve several parameters including calcium, magnesium, COD, BOD_5, chlorides, bicarbonates and carbonates. The results are shown in table-1. Due to the short duration of the experimentation period, there are only three data for each parameter.

The data show that the COD and BOD5 values are lower for surface waters; in effect, wastewaters contain much more oxidizable substances than surface waters, in particular solids in suspension.

The concentrations of magnesium and calcium are relatively higher in wastewaters. These concentrations along with that of sodium are used to determine the absorption coefficient of sodium in water (sodium absorption ration: SAR) given by the formula:

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

For wastewaters, the average SAR is 14.57, which is very high and leads to very large risks on the permeability of the soil.
Total suspended solids (TSS): These substances are not absorbed by the soil and can have an influence on water infiltration and soil quality. Their evolution in waters is indicated by the curves in figure-14. These plots show that TSS are almost nonexistent in surface waters; the only high value observed in the curve may be due to a rain that made the water turbid. However, TSS are high in the treated wastewaters and may cause infiltration problems for soils irrigated with them.

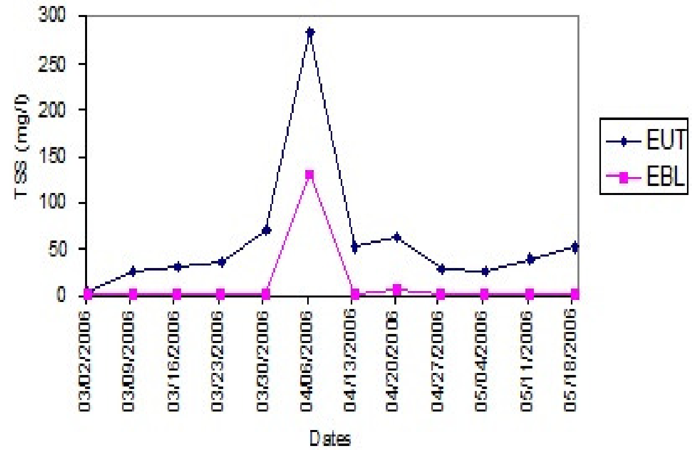

Figure-14
Evolution of TSS in irrigation waters

Physicochemical parameters of the soils: pH and electrical conductivity: These parameters were measured on three soil samples at different locations of each of the four (04) plots. Analyses lead to the results shown in table-2 and table-3. It was found that the pH of both soils is the same, but there is a clear difference in the electrical conductivity. The plots irrigated with the water from the dam of Loumbila have much lower electrical conductivity than those irrigated with wastewaters. With an average of 113.63µS/m for neutral soils, the electrical conductivity of these soils is high enough to prove their salinity[19].

Table-1
Results of monthly analyzes of the waters

	Water from Loumbila			Treated wastewaters of 2iE		
DATE	**03/02/2006**	**04/06/2006**	**05/04/2006**	**03/02/2006**	**04/06/2006**	**05/04/2006**
DBO_5 (mg/l)	20	60	75	70	250	330
DCO (mg/l)	30	20	0	100	160	150
Sulfates (mg/l)	0.8	1	1	29	37	19
Chlorides (mg/l)	7.9	14.01	6	92.1	72.07	37.04
Magnesium (mg/l)	5	2	1	3	3.5	5.5
Calcium (mg/l)	8.8	20	10	24.8	32	16
Bicarbonates(mg/l)	39.04	36.6	48.8	197.64	214.72	231.8
Carbonates (mg/l)	0	0	0	0	0	0

Results of analyses of nitrogen (N) and phosphorus (P) in the soils: These analyses were done at the Laboratory of the National Bureau of Soils in Ouagadougou, Burkina Faso. Data on the concentrations of nitrate, ammonium and phosphorus are reported in table-4 to table-6.

The evolution of nitrates in soils irrigated with wastewaters is similar to that of soils irrigated with the waters of the dam of Loumbila. At the beginning of the experiment, soils were poor in nitrate but its content began to increase with irrigation, showing that there is an intake of that nutrient from the water.

In the case of the phosphorus concentration, soils irrigated with wastewaters showed lower content than those irrigated with the waters from the dam of Loumbila. Then it increased over time. This may be due to the fact that treated wastewaters bring more phosphorus to those soils than surface waters.

Results of granulometric analyses of lettuce plots: These data gathered at the Faculty of Agronomy of Niamey gave the results shown in table-7. They indicate that the soils are not homogeneous with depth[1]. This may affect the infiltration of water. Indeed at the plot C3L, infiltration rate will be lower than that of the plot C2L because at a depth of 20cm, the soil is constituted of 25.5% of clay, while the plot C2L consists only of 24, 05%. The water will stagnate in this plot.

Table-2
Results of analyzes of physicochemical parameters of the neutral plots

Date of sampling	03/11/2006		
Date of analysis	04/20/2006		
Sample	**pH (distilled water)**	**pH (KCl)**	**Conductivity (µS/m)**
C2N1	6.86	5.93	40.5
C2N2	6.46	5.84	54
C2N3	7.27	5.95	42.8
Average	**6.86**	**5.9**	**45.76**
C3N1	7.08	6.15	100.9
C3N2	6.6	5.81	114.2
C3N3	7.04	6.06	125.8
Average	**6.9**	**6**	**113.63**

Table-3
Results of physicochemical parameters of lettuce plots

Date of sampling	03/11/2006		
Date of analysis	04/20/2006		
Sample	**pH (distilled water)**	**pH(KCl)**	**Conductivity (µS/m)**
C2L1	7.74	6.26	47.9
C2L2	7.48	6.49	34.3
C2L3	7.17	6.41	23.5
Average	7.46	6.4	35.23
C3L1	7.58	6.33	83.4
C3L2	7.46	6.28	68.1
C3L3	7.33	6.28	59
Average	7.46	6.3	70.2

Table-4
Evolution of nitrate (NO_3^-) content

Unit: ppm		**Initial state**	**sample n°1**	**sample n°2**	**sample n°3**	**sample n°4**
DATE			04/12/2006	04/19/2006	04/26/2006	05/02/2006
C2L	T	24.46	63.92	28.41	21.31	49.71
C3L	EUT	48.91	78.12	56.82	42.61	42.61

Table-5
Evolution of ammonium (NH_4^+) content

Unit: ppm		Initial state	sample n°1	sample n°2	sample n°3	sample n°4
DATE			04/12/2006	04/19/2006	04/26/2006	05/02/2006
C2L	T	2,43	1.19	1.61	1.05	1.47
C3L	EUT	3,41	0.98	11.52	1.33	2.02

Table-6
Evolution of assimilable phosphorus (P) content

Unit: ppm		**Initial state**	**sample n°1**	**sample n°2**	**sample n°3**	**sample n°4**
DATE			04/12/2006	04/19/2006	04/26/2006	05/02/2006
C2L	T	3.15	16.32	15.45	14.93	16.5
C3L	EUT	1.31	16.84	12.85	16.79	8.33

Table-7
Results of granulometric analyses of lettuce plots

Plot	**Horizons**	**%Clay (< 2µ)**	**% Silt (2 à 50µ)**	**% Sand (50µ to 2mm)**	**%Gross (> 2mm)**	**Type of soil**
C2L	0 - 20	24.05	44.27	31.69	6.59	SILT
	20 - 40	21.53	39.05	39.42	9.60	SILT
	40 - 60	23.16	28.48	48.35	8.42	SILT
C3L	0 - 20	25.50	34.76	39.74	3.36	SILT
	20 - 40	26.48	35.57	37.95	4.29	SILT
	40 - 60	24.83	29.70	45.47	6.24	SILT

Evolution of the ability to infiltration: Six (6) tests were conducted on both soils irrigated with water from the dam of Loumbila and with wastewaters. The corresponding mean values are 2.5 cm/h for the water from the dam of Loumbila against 0.7 cm/h for the treated wastewaters.

Figure-15 and figure-16 illustrate the evolution of the saturated hydraulic conductivity on both soil types. Examination of these figures shows large differences; in fact, the highest values are found on soils irrigated with water from the dam of Loumbila. These differences are probably due to clogging caused by the use of wastewaters. Indeed, the use of wastewaters has caused a change in the organization of the pores in the surface horizons, resulting in a decrease in saturated hydraulic conductivity. Also the very high content of salt in wastewaters leads to a decrease of infiltration capacity, since too much salt in the water causes a decrease in the permeability of the soil and thus a reduction in the rate of infiltration.

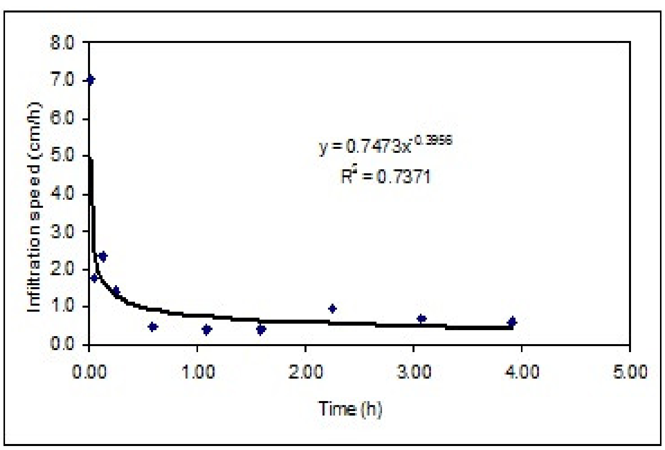

Figure-15
Evolution of the infiltration capacity of soils irrigated with water from the dam of Loumbila

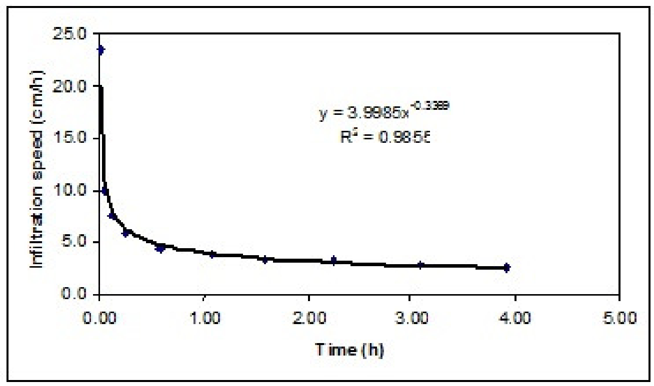

Figure-16
Evolution of the infiltration capacity of soils watered with sewage

Conclusion

The present study aimed to determine the impact of domestic wastewaters on soil. For this, we used the raw water from the dam of Loumbila and domestic wastewaters treated by the process of microphytes lagooning to irrigate land on which lettuce is grown.

The results of the analysis of the physical and chemical parameters of the two soil types lead to the following conclusions: i. Irrigation with wastewaters did not cause significant changes in physical and chemical properties of the soil. However, the high content of certain salts such as sodium in the water leads us to say that the wastewaters must be analyzed continuously to prevent soil salinization. ii. Wastewaters are useful because of their high content in fertilizers for the soil. Indeed, these analyzes showed that the wastewaters contain enough materials to make a soil rich; so they can replace chemical fertilizers which, used for a long term, can lead to premature degradation of soils. iii.

Wastewaters should be properly treated to reduce their content of certain elements to prevent rapid degradation of soils by salinization. iv. The use of wastewaters can cope with the constantly growing needs of populations in water. It is important for us to work to value this resource. Wastewaters are an inexhaustible resource for countries such as Burkina Faso, where rainfall is low; they can replace surface waters used for irrigation. v. The reuse of wastewaters for agricultural purposes helps to fight against pollution because when they are discharged into the environment, they become a source of environmental pollution in the sense that their high nitrates content contributes to the pollution of the atmosphere, due to the nitrogen that is released.

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