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Soil Amendment by Sediment from Water Storage Reservoir as a Restoration Technique in Secondary Treated Wastewater Irrigated Area at El Hajeb Region (Sfax-Tunisia)

Slim MTIBAA[1)], Mitsuteru IRIE[2)], Olfa HENTATI[1)], Habib TRABELSI[3)], Monem KALLEL[1)], Mohamed KSIBI[*1)] and Hiroko ISODA[2)]

Abstract: The negative impacts of irrigation with treated wastewater (TWW) effluents on soils and groundwater aquifer in the vicinity of Sidi Abid Region (Tunisia) is well established. In order to assess the feasibility of sediment utilisation as soil amendment, sediment was extracted from the bed of water storage reservoir, dried and mixed with a soil from the study area at the rate of (35 t/ha). The effects on the soil properties, yield and nutrient contents of Wild OAT (*Bromus ramosus*) were studied. As the most relevant changes, sediment improved the soil water-retention and cation exchange capacity of the mixture, but increased its salinity and heavy metal contents. Yield of OAT increased in parallel with the sediment application whereas OAT growth and yield remained unaffected in the control. Significant effects were also found on the nutrient contents of the plant tissues but no heavy metal accumulation in plants could be detected. According to the results, the application of appropriate rate of sediment to the agricultural soil in El Hajeb seems to be a sound practice to avoid problems of salinity and alkalinity, and to improve the properties of the sandy soils of the area.

Key Words: Effluent from wastewater treatment plant, Salinity, Sediment, Soil amelioration.

1. Introduction

The reuse of treated municipal wastewater is part of the engagement strategy and development of water resources in Tunisia. Consequently, the excessive discharge of the ground water with low quality has occurred, which has imposed a further increase in soil salinization. On the other hand the reduction of water storage capacity of reservoirs in Tunisia because of the accumulation of sediment was reported by Irie *et al.* (2011). He demonstrates that the storage capacity was reduced by 6% from 2000 to 2009. The potential application of sediment as amendment in order to increase soil and crop quality parameters, which are significantly affected by long-term wastewater irrigation, was studied. In this work, the soil from in the vicinity of Sidi Abid Region (south of Tunisia) named El Hajeb irrigated by TWW effluents since 1989, was ameliorated by sediment extracted from Joumine reservoir located on the north area of Tunisia, (50 km from Tunis). The production test of Wild OAT (*Bromus ramosus*) will be carried out on two experimental plots (2m × 2 m each), control and ameliorated with sediment. The production test has been started since October 12, 2010. The effect of soil amelioration by sediment was evaluated with biomass of the products and soil characteristics at growing stage and cropping term.

2. Materials and Methods

2.1. Study site and experimental design

Two cropland sites of four square meters each one, one amended with sediment at the rate of 35 tons of sediment per hectare (normal amount in case of leaf mould fertilization) and the other without sediment using as control, were studied at El Hajeb area (**Fig. 1**), which is located at longitude 10°38'8.34"E, latitude 34°40'47.52"N, 10 km west from Sfax. This site is characterized by arid climate make irrigation essential for crop production (Belaid *et al.*, 2010). The sediment was air dried, grinded and mixed with the surface soil of 15 cm from the top. Then, the plots were seeded with Wild oats (*Bromus ramosus*) and irrigated with 15L/m^2 every 15 days by TWW effluents.

2.2. Soil Sampling / Soil and sediment analysis

From the top soil of each plot, three samples were taken every month, since October 2010. The samples were air-dried in the laboratory and passed through a 2 mm aperture sieve, then analyzed for chemical and physical properties. pH, electrical conductivity (EC), water holding capacity (WHC), organic matter and moisture content were determined by standard methods. Exchangeable cations were measured by

* Corresponding Author: mohamed.ksibi@tunet.tn
Route de Soukra Km 3,5 Po. Box 1173, 3038 Sfax, Tunisia
1) University of Sfax, Laboratory of Water, Energy and Environment, National School of Engineering of Sfax (ENIS)
3) Périmètre irrigué d'El Hajeb route Matar km 9, 3078 Sfax, Tunisia.
2) Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan.

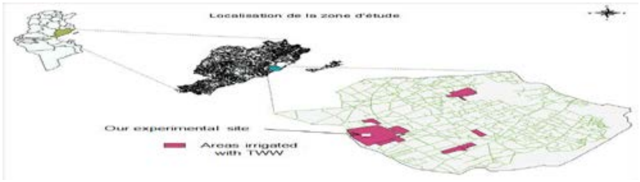

Fig.1. Map of the study area.

using Atomic Absorption Spectrophotometer (ASS) after extraction with 0.5M barium chloride solution. Soluble cations were measured using distilled water instead of 0.5M $BaCl_2$. Heavy metals concentrations were determined by using ASS after aqua regia acid digestion. The mineral composition of sediment was determined by X-ray diffraction (XRD) analysis. Sodium Adsorption Ratio (SAR) was calculated as:

$$SAR_{soil} = Na^{+} / \sqrt{(Ca^{2+} + Mg^{2+})/2} \quad (1)$$

Cation Exchange Capacity (CEC) was calculated as:

$$CEC\ (mEq/100\ g) = Ca^{2+}\ (ppm)/200 + Mg^{2+}\ (ppm)/120 + K^{+}(ppm)/390 + [9*(7{,}5 - pH_{buffer})] \quad (2)$$

2.3. Analyses of growth parameters, biomass and heavy metals in plants

Five plants were selected randomly from each plot, every two weeks, to measure the length. 185 days after sowing, the crop was harvested manually, to preserve each part of grass (root, stoke and leaf, and grain) and stored in polyethylene bags in the laboratory to analyze. Crop total weight was measured after washing plants and then air drying in the laboratory, total fresh weight was expressed as $g.m^{-2}$. For heavy metal analysis, oven-dried plant parts samples were homogenized by grinding in stainless steel blender and then passed through a sieve of 2 mm mesh size. Grinded sample of 1g was digested in 20ml tri acid mixture (HNO_3:H_2SO_4:$HClO_4$:5:1:1) till a transparent colour appeared. Heavy metal concentrations were determined in the filtrate by using AAS.

2.4. Reproduction test with springtails *Folsomia candida* and Oligochaeta *Enchytaeus albidus*

Reproduction test with *F. candida* was performed according to the OECD 232 (2009) guideline. Each replicate consisted of a glass container filled with 30 g (dry weight) of natural soil amended with different percentages of sediment (10%, 20%, 30%, and 40%), in which 10 synchronized juvenile springtails (10-12 days old) were introduced. Again, control treatment was made with natural soil only. The number of surviving adults and juvenile were determined after 28 days.

Reproduction test with *E. albidus* was performed according to the OECD 220 guideline (2004). Test procedure is similar to springtails test. Statistical analysis was performed with the SPSS software package (version 19.0.0). One-way Analysis of Variance (ANOVA) and least significant difference (LSD) test were performed to compare the reproduction levels of soil animals between control soil and amended soils (10% to 40%).

Table 1. Physic-chemical characteristics of sediment.

Characteristic	Value
pH	7.37
EC ($\mu S.Cm^{-1}$)	967
Organic content (% dry weight)	7.17
CEC (mEq/100g)	111
Exchangeable cations ($meq.Kg^{-1}$)	
Ca^{2+}	370
Mg^{2+}	63.16
K^{+}	6
Na^{+}	7.62
Soluble cations ($meq.Kg^{-1}$)	
Ca^{2+}	14.82
Mg^{2+}	6.33
K^{+}	4.8
Na^{+}	6.73

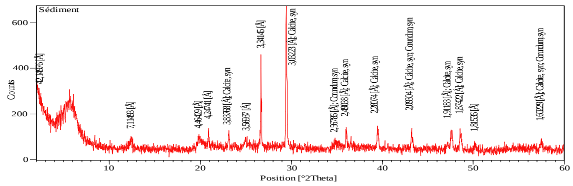

Fig.2. the XRD pattern of Sediment with d space.

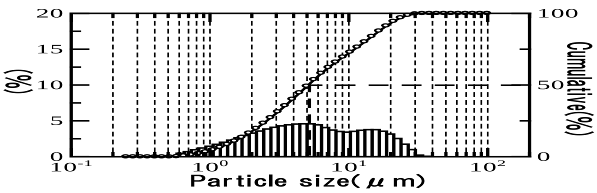

Fig.3. Particle size cumulative curve.

3. Results and Discussion

3.1. Sediment characteristics

3.1.1. Physic-chemical characteristics of sediment

Table 1 shows the physic-chemical properties of the sediment. The pH was neutral equal to 7.37, the EC was very high which is due to the presence of high amount of salts and cations. The sediment is characterized by a high CEC equal to 111 mEq/100g due to clay content and organic matter. The high CEC allows plants to resist against stress. Sediment is very rich in calcium as shown by exchangeable cations. The high level in calcium indicate the presence of carbonate as calcite as confirmed by the XRD analysis (**Fig. 2**).

Figure 3 shows the particle distribution of the sediment. The median particle size of sediment is 5 μm which indicates that the sediment in Joumine reservoir is quite fine clay and moderate organic contents (Irie *et al.*, 2011).

Table 2. Heavy metals concentration in the sediment

Heavy metals	Value in sediment ($mg.Kg^{-1}$)	NFU 44-051 ($mg.Kg^{-1}$ DM)
Cu	14.75 ± 0.25	300
Pb	28.5 ± 0.75	180
Ni	25.5 ± 1.75	60
Zn	95.75 ± 2.75	600
Fe	19991 ± 435	-
Cd	1.5 ± 0.25	3
Co	44 ± 1.25	-
Mn	270 ± 13	-

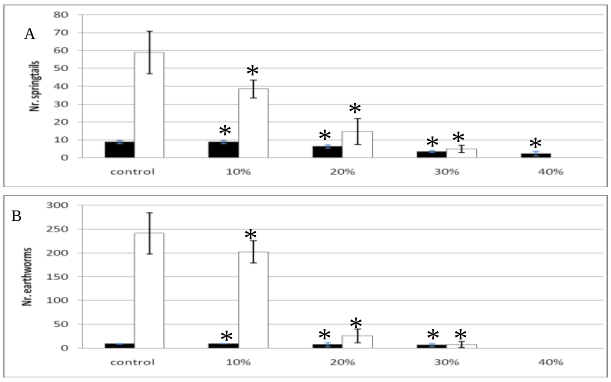

Fig. 4. Reproduction tests with *F. candida* (A) and *E. albidus* (B). Number of adults in soils (black bars). Number of juveniles produced in soils (white bars). Values are means +SD. "*" indicates significant statistical differences ($P < 0.05$) from control soil.

3.1.2. Heavy metals in the sediment

In sediment, mean metal level (Cu, Pb, Ni …) were generally higher. This could be as a result of adsorption to sediment particles. Some of these elements are essentials for the growth of plants whereas others are not essentials. The values of the metals content quantified in the sediment (**Table 2**) are in conformance with a statutory norm (e.g. norm NF 44-051 on organic fertilisers). Thus the sediment can be used as a soil amendment to add organic matter to disturbed soils.

3.1.3. Risk characterization of sediment

In the two reproduction tests (**Figs. 4** A and B), the numbers of springtails and earthworms juveniles, decrease with the increasing percentages of sediment. This is due to the chronic effect of heavy metals present in the sediment, affecting the reproduction function of animals. In fact, at 40%, neither springtails nor earthworms juveniles were counted. It is worthy to note, that at this concentration the sediment changed the structure of amended soil due to its high content in clay. Consequently, the soil becomes an unfavourable environment for housing these invertebrates. A significant higher decrease of number of springtails and of earthworms (adults and juveniles) after 28 days was found on both amended soils (10- 40%).

3.2. Effects of sediment on soil characteristics

3.2.1. Evolution of soil electrical conductivity

Soil salinity, measured as EC in both control soil and soil

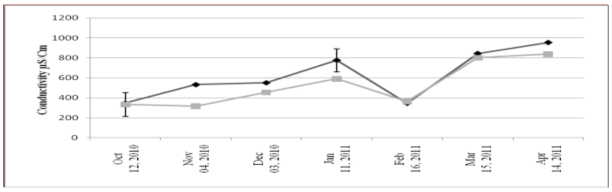

Fig. 5. Evolution of the EC in control soil (grey line) and in soil amended by sediment (dark line).

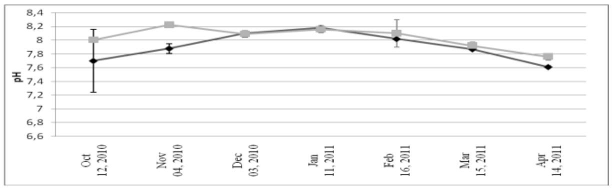

Fig. 6. Evolution of pH in control soil (grey line) and in soil amended by sediment (dark line).

amended with sediment show significant increasing of electrical conductivity with time after irrigation with TWW. This could be attribute control soil extract in used to the original high level of total dissolute salt of the wastewater. At the same time the effect of evaporation, salt in the soil was moved to the surface and raise soil EC. However, the EC rise of soil amended by sediment is higher than that of control. It seems that soluble cations in the sediment perform the function of soil amelioration.

3.2.2. Evolution of soil pH

The effect of TWW irrigation on soil pH is not constency. It has been reported by Schipper *et al.* (1996) that soil pH increased following long term TWW irrigation and they attributed this increase to the chemistry and high content of basic cations such as Na^{+}, Ca^{2+} and Mg^{2+}. Regarding the obtained results in term of the variation of pH versus time in soil amended with sediment and control soil, on the last day of our experiment, the pH of amended soil is equal to 7.6 however, it is about 7.8 for control soil. Also, the SAR of amended soil (0.7) is smaller than that of control soil (0.8). It seems then that the sodium ratio in control soil is greater than that in amended soil. Alkalinity soil is due to the presence of salt (carbonates of calcium, magnesium and sodium) comparatively in high degree. This problem is corrected by using sediment as shown in **Figure 6**. The soil amended with sediment is less alkaline than the control soil. Consequently the sediment contributes to the neutralisation of the alkalinity caused by irrigation with TWW.

3.2.3. Evolution of soluble Calcium concentration

Except the result of Feb, 16 and Mar, 15, sediment reduces the soluble Ca^{2+}. Perhaps it's due to the change of physical structure of soil. Sediment is originally clay, finer than original soil of El Hajeb. It's diversifying the particle distribution and aggregation. So, sediment improves the air and water permeability. As a result, soluble Ca^{2+} was washed

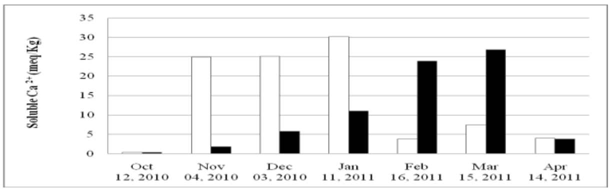

Fig. 7. Evolution of soluble Calcium: in soil amended by sediment (darck bars) and in control soil (white bars).

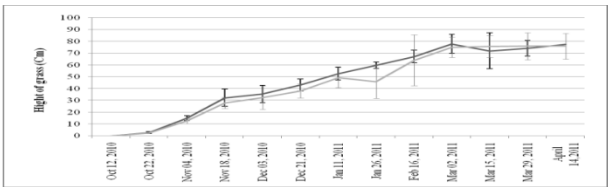

Fig. 8. Evolution of grass height in control soil (grey line) and soil amended with sediment (dark line).

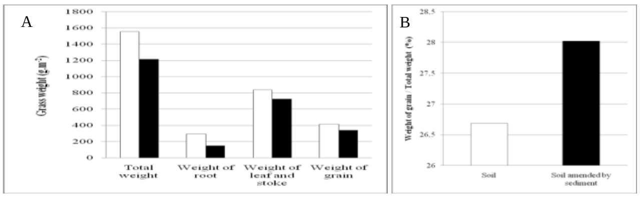

Fig. 9. A: Crop weight in control soil (white bars) and in soil amended by sediment (dark weight). B: Report between weight of grain and total weight in control soil and in soil amended by sediment.

Table 3. Heavy metals value in plants seeded in the soil amended by sediment (Soil1) and control soil (soil2). Values were in mg/Kg

metals	Value in roots		Value in shoots		Value in grain	
	Soil1	Soil2	Soil1	Soil2	Soil1	Soil2
Cu	11.3	13	3.52	3.512	5.046	8.122
Pb	5.264	1.84	ND	ND	ND	ND
Ni	6.1	3.71	ND	ND	ND	ND
Zn	89.03	49.342	43.072	32.224	37.8	49.17
Fe	2198	2115.64	40.528	44.25	37.2	25.4
Cd	0.428	0.342	ND	0.272	ND	ND
Co	1.448	2.652	ND	1.26	ND	ND
Mn	41.6	66	14.456	39.49	6.46	9.078

by the irrigated water and the accumulation of soluble cations on surface was reduced by evaporation. Discussion on sediment (cations of pure sediment) characteristics is high content of exchangeable Ca^{2+} in comparison with El Hajeb soil (sandy).

3.3. Effects of sediment on biomass parameters

3.3.1. Evolution of grass height

In the presence of sediment as soil amendment the growth of Wild OAT (*Bromus ramosus*) is better than for control soil. It seems that the humic substances in the sediment perform the function of soil amelioration.

3.3.2. Crop weight

Total weight of biomass is higher in the control site than in the site amended by sediment. However, the report about weight of grain and total weight is about 28% in the site amended by sediment and 26% in the control site.

3.3.3. Accumulation of heavy metals in plants

The application of soil amendments favours plant growth. Sediment amendment application led to an effective immobilization of Pb, Cu, Zn and Cd phytoaccessible forms in soil. It led to decrease heavy metal content in Wild OAT parts. However the accumulation of heavy metals is well observed in roots of plants growing in soil amended by sediment. This latter is especially effective for reduction of the Cu, Zn and Mn contents in Wild Oat parts. The sediment amendments are of great interest for the purpose of phytostabilization.

4. Conclusion

Amendment with sediment extracted from the bed of water storage reservoir enriches the soil with organic matter as well as improves its structure and physical properties. The results of this experimental study show that organic acids (presumably humic or fulvic acids) can dissolve from the sediment and destroy soil alkalinity (pH=8.2). Soluble calcium is significantly increased by about 20 mequiv.kg^{-1} of soil. Ecotoxicological tests included earthworm (*Enchytaeus albidus*), 28 days survival show that the sediment at higher percentage has negative effects on the soil individuals because it is very clayey, thus the soil becomes an unfavorable environment for housing for individuals. Heavy metals concentrations in sediment are acceptable and no accumulation has been observed in the different parts of crop. Significant differences were observed in heavy metal concentrations in the plants seeded in the soil amended with sediment compeered to the control soil. Heavy metal content in soil and plant tissues of Wild OAT decreased significantly compared with those without sediment which play role of chelating agents.

Acknowledgement

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