BIOSOLID RECYCLING TO ENHANCE CARBON SEQUESTRATION IN MOUTAINOUS LEBANESE CONDITIONS

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ABSTRACT

In Lebanon, the great majority of wastewater is dumped wildly into streams, wells or the sea. Eventually treated sludge will be produced across the country and disposed of, to a great extent, on land. This disposal obeys rules and regulations in most countries. In this work, on the results of the application of a biosolid on the carbon balance in two contrasting soils are reported. The biosolid that originated from a small plant treating domestic wastewaters did not contain high concentrations of heavy metals. Biosolids were applied in two levels (S1: 3.75 tons ha^{-1} and S2: 7.50 tons ha^{-1}) to a loamy sand (Kfarhim) and a calcareous loam (Baakline). The incorporation in early October was immediately followed by the sowing of a barley cover crop. Sludges increased the barley production in the fast draining loamy sand only. In parallel, the in-situ decomposition studied during the rainy seasons gave a carbon loss of 21.8% (Baakline) and 29.1% (Kfarhim) of the initial sludge C. In the short-term, studies showed that 15 to 31 % of the carbon of biosolids will remain in soils. This could significantly contribute to carbon sequestration, particularly in slow-draining soils.

Keywords: biosolid, calcareous loam, loamy sand,carbon emission

INTRODUCTION

In Lebanon, wastewater is a source of public nuisance, environmental and health threat. The great majority of generated wastewater is dumped wildly into streams, water or to the sea. Some 190 Mm^3 of untreated wastewater are discharged daily to the sea (Anonymous, 2005) while 2 Mm^3 are used yearly in irrigation (Aquastat, 2007) including of fresh vegetables (Dib & Issa, 2003). Only few localities are currently treating the sewage water, with a daily generation of 16 000 m^3 of treated water. In addition to the 31 operating plants, 33 others are planned (Geara *et al.,* 2010). Wastewater reuse is a valuable option in countries where water resources are scarce. Within the Near East countries, the first country that recycles the treated water is Egypt, followed by Syria, United Arab Emirates and Saudi Arabia (Bazza & Xanthoulis, 2010). In order to protect the food chain and the natural resources, this reuse must obey the country's regulations. The Lebanese ministry of environment, in an attempt to control air and water pollutions, produced environmental guidelines (ministerial decree 1/52 - July 1996; revised as 8/1 in January 2001). Yet, the aspects related to the solid phase do not seem covered by these regulations.

One of the most common means of disposal of generated biosolidis land application. In the USA, half of the biosolids is recycled on land, while in Europe this varies from 10% in Sweden to 80% in Portugal (UNEP, 2002). This disposal obeys regulations that aim to reduce the risk factors while providing the safe practices that control and minimize these risks. The best management practices concern the land (slope, distance from housing and streams…), the crop and managerial aspects related to the timing of application in relation to the harvest time for instance, the amount allowed as a single addition, the time allocated between successive inputs.

Orchards and forests are the most probable sites for the disposal of treated sewage, as the consumed parts are not in contact with the ground at all. Agricultural lands represent 34.2% of the Lebanese territory, with half of it (48.5%) corresponding to orchards (Anonymous, 2005). Covering 58 531 ha (Abou Zeid, 2007), olive orchards are mostly in terraces. Although the olive tree performs better on a deep well drained soil, it can adapt easily to poor calcareous soils (Lteif *et al*., 2006) with a low fertility. It can also tolerate a wide range of pH. The calcareous soils seem adequate for sludge application as the high calcium carbonate stabilizes the organic material. Therefore, olive orchards might be a suitable cover for the reception of biosolids. It is not known if some trials have dealt so far with sludge application under Lebanese conditions. Based on this, a two-year trial was conducted on the fate of a biosolid in a sandy soil and a calcareous loam soil, traditionally considered poor in organic matter. The investigation involved one aspect related to the overwinter nitrogen mineralization in the two contrasting soils (Atallah *et al*., 2011). This study reports on the carbon balance, and discusses the managerial aspects of sludge application to enhance carbon sequestration under humid Lebanese Mediterranean conditions.

MATERIALS AND METHODS

Sludge: origin and analysis

The biosolid originated from a small plant operating in Baadarane (33°38’09 N, 35°37’09 E, 1000 m) in the higher Chouf. Wastewater collected from the village houses was thoroughly mixed then separated into the liquid phase and the sediments. Solid particles were sent into three maturation ponds. Layered with a thin layer of gravels, their role was to trap the solid particles forming a thin layer of sewage. The shallow depth allowed it to get oxygenated and therefore treated. After exposure to the summer sun for around 3 months, the crusted sewage was mature.

Sludge samples were collected in early October. Subsamples were air-dried then finely ground before ashing. Phosphorus and Kjeldhal nitrogen were determined according to the methods described by Ryan *et al*. (2006). The carbon content was calculated from the following relationship based on the ash content (Robin, 1997):

$$C\ (\%) = 47.82 - 0.387 \times \text{ash}\ (\%)$$

The water-soluble organic carbon was obtained after extracting, in triplicates, 10 g of sludge in 100 mL of distilled water for 30 minutes, on a horizontal shaker at room temperature. The suspension was filtered (n°42 Whatman paper), then the filtrate was dried at 70°C. The dry sample was weighed and a subsample used to determine the organic carbon was treated with potassium dichromate and concentrated sulfuric acid, and the mixture was heated for 30 minutes at 150°C (Wu & Ma, 2001). Heavy metals (asbestos, cadmium, cobalt, copper, lead, nickel, selenium and zinc) contents were analyzed at the Lebanese Atomic Energy Commission (CNRS).

Experimental site and analysis

A loamy sand (Kfarhim: 33°44'13 N, 35°31'23 E, 497 m) and a strongly calcareous loam (Baakline: 33°40'06 N, 35°31'47 E, 797 m) were selected. Soil properties were contrasted in terms of their texture and calcium carbonate content. The loamy sand was dominated by the sand fraction (84.72%) and the calcareous loam by silt (41.16 %). The Baakline soil was strongly calcareous (55% of $CaCO_3$; pH of 7.85) while that of Kfarhim presented 2.1% of $CaCO_3$ and a pH of 7.52. The soil organic carbon content (0-15 cm) was 9.7 g kg^{-1} soil in Kfarhim and 14.6 g kg^{-1} in *Baakline*. Both terraced locations were occupied by olive trees. Climatic data were those of the nearest meteorological station of Deir El-Kamar (33°41'85 N, 35°33'87 E, 850 m), as obtained from the Civil Aviation directorate. Deir El-Kamar receives 950-1100 mm of rainfall for a mean annual temperature of 17.35°C. The minimum and maximum daily temperatures between December 3rd and March 28th of both years (Figure 1) indicate higher temperature range during the first year.

Sludge was applied in U-shaped strips around olive trees in two rates in early October and at a distance of 1.5 m from the trunk. The biosolid covered a surface of 4 m^2 $tree^{-1}$. Assuming a density of 250 trees per hectare, the amount of sludge reached 3.75 Mg ha^{-1} in the S1 treatment and 7.50 Mg ha^{-1} in the S2 treatment (Table 1) the equivalent of 165 kg N ha^{-1} in S1 and 329 kg N ha^{-1} in S2. Sludge was immediately incorporated down to 15 cm, followed by broadcasting of barley seeds (100 g $tree^{-1}$). The number of replicates was 4 in Kfarhim and 5 in Baakline. Every replicate was represented by two trees.

Barley sampling was done by taking two quadrates (30 x 60 cm) per tree, just before spring plowing. This coincided with March 23rd in Kfarhim and April 11th in Baakline. The shoots biomass was determined after drying the fresh material at 60 °C. Roots biomass was calculated using a shoot:root ratio of 6:1, while the carbon content was considered equivalent to 45% of dry matter (Plante & Parton, 2007).

Soil was sampled in two depths (0-15 and 15-30 cm) from the U-strips having received the sludge. One composite sample was collected from each replicate. Oxidizable soil organic carbon was determined by wet oxidation followed by heating at 150°C for 30 minutes (Nelson & Sommers, 1982). Available phosphorus was obtained using the Olsen method, by extracting with sodium carbonate at a pH of 8.5 (Ryan *et al*., 1996). Statistical analysis consisted of the analysis of variance using Sigmastat (Jandel Scientific).

***In-situ* carbon decomposition**

The biosolid decomposition in the soil was studied using the bag technique. Nylon bags (mesh size *ca* 1 mm) containing known amounts of sludge were buried at 15 cm depth in each site. Incorporated at first in October 2005, the bags were unearthed in December 2005 then in March 2006 (Kfarhim) and April 2006 (Baakline). Similarly, a new set of bags was incorporated in December 2006 and sampled in March 2007.

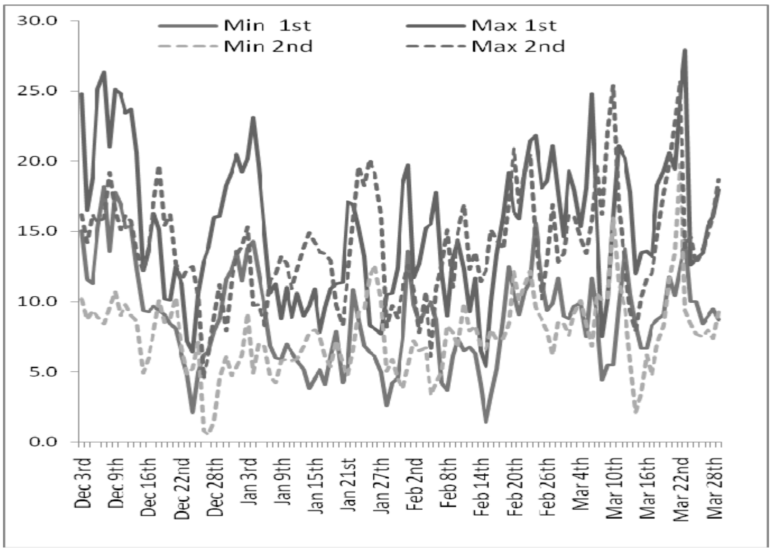

Figure 1. Minimum and maximum daily temperatures recorded in Deir el-Kamar station during the first (December 2005-March 2006) and second (December 2006-March 2007) years.

TABLE 1

Amounts of Sludge Applied in Both Sites and of Carbon Trapped in the Barley Cover Crop Grown for 188 Days in Baakline and 164 Days in Kfarhim

Site	Treatment	Sludge		Barley		
		Dry weight	Organic carbon	Shoots dry matter	Shoots + Roots*	Carbon*
		kg ha^{-1}				
Baakline	Control	0	0	10 673	12 452	5 603
	Sludge 1	3670	1353.9	10 521	12 274	5 523
	Sludge 2	7340	2707.7	11 494	13 410	6 034
Kfarhim	Control	0	0	9 893	11 542	5 194
	Sludge 1	3750	1383.4	14 659	17 102	7 696
	Sludge 2	7500	2766.7	13 097	15 280	6 876

*By calculation (Plante & Parton, 2007).

Four bags were collected every time, from each location. Sampled bags were dried around 50°C. Then the remaining material was carefully extracted before weighting it and grinding it for further analysis. The amount of organic carbon was obtained by ashing in a muffle furnace (550°C for at least 8 hours).

RESULTS AND DISCUSSION

Sludge quality

The chemical analysis of the biosolid presented, on a dry weight basis, 43.9 g kg^{-1} of Kjeldhal nitrogen, 12 g kg^{-1} of total phosphorus (P), 6.7 g kg^{-1} of potassium (K) and 282.5 g kg^{-1} of ash. Based on the ash content, the carbon content was calculated as 368.9 g kg^{-1}, instead of 398.6 g kg^{-1} established using the 1.8 correction factor on the organic matter content. The C:N ratio of the biosolid was 8.4, a low value, characteristic of treated sludge (Robin, 1997).

The biosolid issued from housing wastewater did not contain high concentrations of heavy metals, except for zinc (Table 2). Its composition was well below the limits set by the European Union and the United States Environmental Protection Agency (USEPA).

TABLE 2

Heavy Metal Composition of the Biosolid from Baadarane Station and the Limits Set by the European Union and the United States Environmental Protection Agency (USEPA), According to Webber and Sidhwa (2007)

	Concentration (mg kg^{-1} of dry matter)		
Element	**Baadarane sludge**	**European Community limit**	**USEPA “no adverse effect”**
Asbestos	8	-	41
Cadmium	0	10	31
Cobalt	0	-	-
Copper	248	1000	1500
Nickel	29	300	420
Lead	119	750	300
Selenium	0	-	100
Zinc	2054	2500	2800

Sludge management

The sludge application in early October was accompanied by the planting of a barley cover crop. The aim was to have a sink that absorbs the released nutrients, especially nitrogen. The environmental conditions were, then, suitable for the mineralization of the nitrogen and for the percolation movement within the soil. Between mid-November and mid-December the air temperature was still above 10°C, high enough to sustain microbial activity in the soil as long as soil moisture was available. Moisture in soil was provided by the rain events (178.9 mm of rainfall) recorded in Deir-El-Kamar between October 2005 and mid-November. Therefore, both soil moisture and temperature were favorable to soil mineralization and to potential leaching of nitrogen and phosphorus.

In the absence of local regulations related to the amounts and frequency of application, reference is made to those established elsewhere. To avoid uncontrolled losses of nitrogen, the regulation in the United States limits the application of biosolids to the agronomic rate, as long as there is no heavy metal restriction (USEPA, 2007). This agronomic load or rate meets the crop requirements, assuming that 30% of the total nitrogen is available in the first year (Evanylo, 2003). The Canadian regulations restrict the input to 30 Mg of dry matter over a 10-year period, as long as the amount of available nitrogen does not exceed 135 kg N ha^{-1} over 5 years (Anonymous, 1991). Based on this, the S2 treatment corresponds to 99 kg of available N, which is within the allowed limit. For this treatment, one further application equivalent to 2.70 t ha^{-1} would be acceptable within the next 5 years.

Soil quality

Soil pH was measured in the last sampling, before spring plowing. No significant difference was found within each site but Baakline showed slightly higher results than Kfarhim due to the calcium carbonate contents. However, the overall mean remained in the same range. The pH slightly decreased with time reaching 7.27 in Kfarhim and 7.36 in Baakline. This change was not significant compared to the initial pH which confirms the finding that the application of sewage to the soil does not have any significant effect on the initial pH (Casado-Vela *et al.*, 2006).

For the electrical conductivity, there was no significant difference between treatments in Kfarhim. In Baakline, however, a significant difference was obtained between the treatment S2 (0.13 dSm^{-1}) and the control (0.10 dSm^{-1}) in April 2006. This result could be explained by the high amount of N, P and K released from the sludge. This difference occurred only in the calcareous loamy type of soil that helps in retaining minerals, especially phosphorus (Ojekanmi, 2010).

Soil phosphorus measured in two depths (0–15 cm and 15–30 cm) showed a great variability among replicates of a treatment. No significant difference was found neither in depth nor between treatments in Kfarhim (Table 3). Yet in Baakline, the Sludge2 treatment provided higher P concentrations compared to Sludge1 and the control. This is strictly related to the higher dose of phosphorus applied in the Sludge2 treatment and to the slower movement of available P in the calcareous soil.

In Baakline as in Kfarhim, there were no differences between depths (Table 3) despite a relatively higher concentration in the upper layer (0-15 cm). In fact, a single sludge application could not lead to a significant change in the soil characteristics. It was after 33 years of manure application that the P concentrations increased in soils (Ojekanmi, 2010).

TABLE 3

Soil Available Phosphorus (mg kg^{-1} Dry Soil) in Two Depths in Kfarhim and Baakline before Spring Plowing in 2006

Baakline (April 11th)		**Kfarhim (March 20th)**		**Treatment**
15 – 30 cm	0 - 15 cm	15 – 30 cm	0 – 15 cm	
54.7	41.3^{b}	51.4	36.8	Control
36.9	57.5^{b}	45.2	85.6	Sludge 1
36.7$^{\Diamond}$	127.3$^{a\Diamond\Diamond}$	46.8	70.6	Sludge 2
42.7	75.4	47.8	64.3	Mean

Within one row/column, values followed by the same symbol are not significantly different ($p<0.05$).

***In-situ* decomposition and C balance**

Next to phosphorus, the addition of sludge leads to the decomposition of a fraction of the organic carbon. The loss of organic matter was demonstrated through the increase in the ash content equivalent to 59.5% in Kfarhim and 41% in Baakline (Table 4). During the fall and winter seasons, carbon loss reached 21.76% in Baakline and 29.14% in *Kfarhim* (Table 4). The majority of this loss (*ca* 78%) occurred during the first period of burial between October and December 2005, due to the removal of the labile C fractions and to the soil water and temperature favorable to the microbial activity. In the same conditions, the nitrogen loss was slightly larger (Atallah *et al*., 2011) due possibly to the low C:N ratio of the product and to the easily decomposable nitrogen compounds reaching 30% of the initial nitrogen in the first year. The duration of the burial covered between 76% (*Kfarhim*) and 85% (*Baakline*) of the annual precipitation recorded between October 2005 and October 2006. This corresponds to the majority of the positive water balance.

In 2007, the burial time corresponded to the winter season only. During this time, the rainfall was smaller (536.4 mm *versus* 725 mm in 2006) and the degree-days lower (190.6 *versus* 295 in 2006). In brief, the 2007 season was drier and cooler than the previous season (Figure 1) leading to a more restricted microbial activity. As a result of the shorter duration of incubation and the harsher climatic conditions, the amount of C lost ranged between 3.8% and 8.1% (Table 4), the equivalent of 22% of the quantity of C lost during the 1st year. Yet, these values exceeded the water-soluble organic C (1.51%) suggesting a reduced activity on the labile C fraction.

This *in-situ* approach gives the rate of decomposition in the short-term (Figure 2). The prediction of the resistant C fraction is still under investigation. In replacement of the medium to long-term field studies, the objective is to evaluate it by biochemical or respiratory methods (Lashermes, 2010). One of them consisted of a biochemical fractioning (soluble fraction, hemicelluloses, cellulose, lignin). Using this analysis for biosolids, the average C fraction remaining in soils, 5 to 10 years after incorporation, was close to 20.4% with a range between 15 and 31% (Robin, 1997). The value in Kfarhim soil could be in the second quartile

(19%) while that of the Baakline soil may reach 25%. According to the amount initially added in the S1 treatment, the remaining carbon might be close to 266 kg C ha^{-1} in Kfarhim and to 338 kg C ha^{-1} in Baakline (Figure 2).

TABLE 4

Changes in Dry Matter, Ash Content, Organic Carbon and Carbon Loss from the Bags Buried in Kfarhim (K) and Baakline (B) in the 2006 and 2007 Seasons

C loss (% input)	Organic C (g kg^{-1})	Ash content (g kg^{-1})	Dry matter (g)	Rainfall (mm) [degree-days]	Site	Time
0	**377.6**	**260.1**	**1000**	**0**	**K/B**	**Oct '05**
22.84	319.1	411.1	913	275 [341.5]	K	Dec '05
17.17	353.0	323.6	886		B	
29.14	317.7	414.8	842.2	1000.7 [636.1]	K	Mar '06
21.76	336.3	366.7	878.5	1124.7 [728.9]	B	Apr '06
0	**358.85**	**304.0**	**1000**	**0**	**K**	**Dec '06**
		311.9			**B**	
8.06	349.91	331.5	945.8	536.4 [190.6]	K	Mar '07
3.79	357.3	312.4	962.6		B	

The estimation of the carbon balance can not overlook the amount fixed by the barley cover crop from the atmosphere. The presence of sludge promoted slightly larger plant biomass (Table 1). The fraction of plant material resistant to decomposition was studied in four Australian soils using labeled carbon. After 8 years of incorporation, 11 to 13% of the original C persisted in soils (Ladd *et al*., 1985). Under the conditions of the present study, a value of 13% for Baakline soil and 10% for Kfarhim soil is a fair estimate. Thus, in the medium-term the Baakline soil will retain 1096 kg ha^{-1} of organic C against 1022 kg ha^{-1} in Kfarhim (Figure 2).

Despite smaller initial C, the calcareous loam site may accumulate more organic carbon as a result of its physical and biological properties, despite a greater carbon input in Kfarhim (8969 *versus* 6798 kg of organic C ha^{-1}).

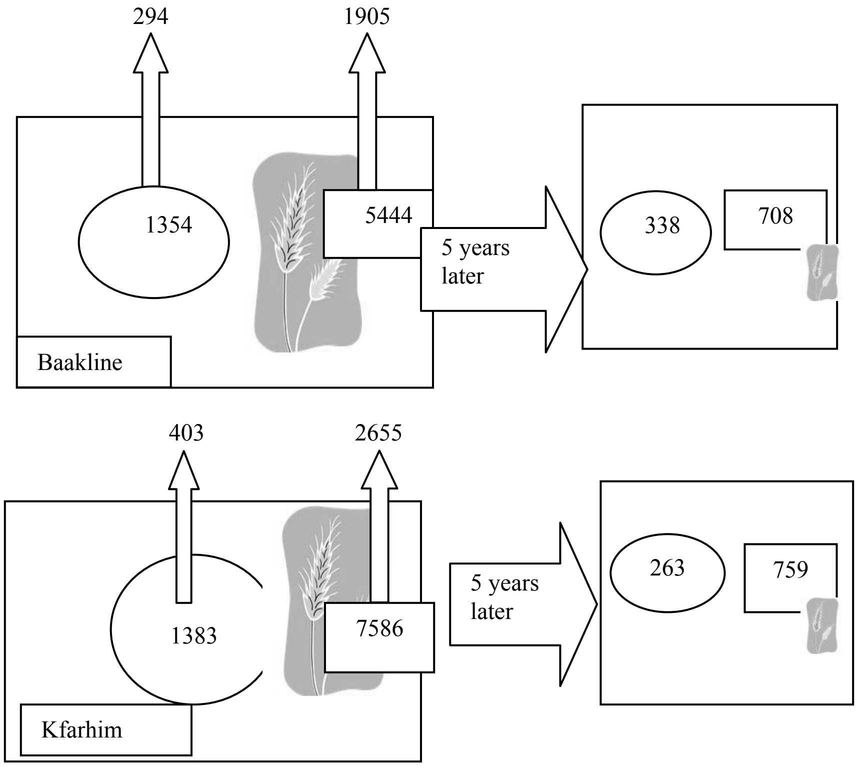

Figure 2. Representation of the fate of carbon (kg ha^{-1}) from sludge and the barley crop during the first year (left) and 5 years later in Baakline (upper) and Kfarhim (lower) soils.

CONCLUSION

Biosolid was tested in a loamy sand and in a calcareous loam. The sludge addition had to be done in early fall, for this a cover crop was necessary to avoid uncontrolled losses from the soil-plant system. Growth of the barley cover crop was faster in the loamy sand than in the slow-draining calcareous loam. The addition of sludge improved the growth of the cover crop. The amounts of sludge tested in this work are agronomic doses, compatible with the practices of Lebanese growers. Sludge contribution to phosphorus, nitrogen and carbon balances may be beneficial.

Recycling biosolids to land (orchards, forest, marginal lands...) when carried out according to the regulations is a sustainable option. Land disposal of the biosolids generated by 2.5 millions Lebanese inhabitants will give an annual load of 25 000 tons of C, considering an annual production close to 27 kg capita^{-1} (Robinson *et al*., 2011). Assuming an average ash content of 30% and that 21 % of the initial C remains in soils after 5 years, the quantity of carbon will be 5250 tons. This amount would significantly contribute to the soil organic carbon and may partly compensate for the carbon emitted annually by the mobile and stationary combustions in Lebanon.

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