Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.926260

55 (2015) 1152–1166
July

Taylor & Francis
Taylor & Francis Group

Study of the prospects for agricultural utilization of sludge produced from WWTPS in North Central Algeria

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Received 25 November 2013; Accepted 8 May 2014

ABSTRACT

The objective of this study is to investigate the sewage sludge of six wastewater treatment plants (WWTPs) in North Central Algeria for agricultural reuse. After a brief description of the region (climate, distribution of soils, and crop types), a quantitative and qualitative examination of the sludge produced was conducted in addition to a comparative study of urban compost and cattle manure. The selected agronomic parameters were dryness, percentage of organic matter (OM), as well as the contents of nitrogen, phosphorus, potassium, and calcium. An average OM of soils of 1.3% and a minimum value of 0.2% made it clear that the urgency of providing this type of amendment was warranted. The sewage sludge in this study was characterized by carbon to nitrogen ratios lower than those of manure and compost due to its stabilization process at the WWTPs on one hand, and the presence of recalcitrant lignin compound mineralization in compost and manure, on the other hand. The spreading of sludge in the region covered a very small surface area, not exceeding 0.50% of the overall agricultural area. The quantities of fertilizers produced by sludge were significant and often exceeded agricultural requirements. Yet, due to the insufficient amounts of OM provided by sewage sludge, there was a need to rely on alternate sources such as manure and/or urban compost.

Keywords: Recovery; Sludge; Organic matter; Fertilizers; Safety

1. Introduction

Currently, the sustainability of agricultural production represents a major challenge for agricultural activity [1]. Soil richness in organic matter (OM) is one of the main indicators of soil fertility. It also represents a characteristic which is more appreciated in a global context of climate change where the storage of carbon in soils is an alternative for reducing atmospheric CO [2]. In Algeria, organic soil reserves have undergone several transformations due to the effect of intensive use of natural resources with very low restitutions of crop residues and organic amendments. It is logical then as recourse, to enhance sludge by returning it to

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the soil within the limits of its storage ability without altering its functions, avoiding the diffusion of contaminants which would be difficult to control. Our investigation is limited to six wastewater treatment plants (WWTPs) of urban WWTPs representative of the North Central Algerian region, with techniques which rely on biological processes (activated sludge). WWTPs have many attractive properties for agriculture, as sewage sludge has a potential of providing OM and nutrients for agriculture, however, they can also be a source of pollution. The widespread use of sewage sludge would be based on the lifting of a number of restrictions, namely those related to the presence of heavy metals and organic trace compounds (OTCs). The objective of this study is to assess sewage sludge of North Central Algeria (Mitidja region) in qualitative and quantitative terms and predict the consequences of their use on the environment and human health [3].

2. Materials and methods

2.1. Climate, study environment, and timeline

The climate in the North Central Algerian Mitidja region is sub-humid Mediterranean, with two seasons: a cold and damp season, occurring generally between September and May, and a warm and dry season that extends from June to August. Rainfall is variable, and by comparison, the average 10 year rainfall of 1997–2007 had a mean of 540 mm while between 1967 and 1977, the average rainfall of region had a mean of 790 mm. In 2008, the average was 640.4 mm (Amer El Ain WWTP) [4]. The Mitidja region has a fairly homogeneous climate with no major differences in temperature [5]. With a total area of 1,400 km^2 and an agricultural area of approximately 120,000 ha, this region encompasses the provinces of Algiers, Blida, and a partial area of both Tipaza and Boumerdes. Sewage sludge, the subject of this study, originates from the biological treatment plants which treat wastewater from urban agglomerations, including domestic sewage, industrial water, and run-off from WWTPs of six different cities (namely Beni-Messous, Boumerdes, Kolea, Medea, Reghaia, and Tipaza) within the Mitidja region. The cities of Boumerdes and Reghaia are located at 50 and 30 km East of Algiers (capital of Algeria) respectively, while Beni-Messous, Kolea, and Tipaza are located between 30 and 75 km West of Algiers [5]. With the exception of Medea which is located inland at a 100 km South of Algiers, the five other cities are located in the coastal Mediterranean zone, between the provinces of Tipaza and Boumerdes. Table 1 shows the hydraulic characteristics of the six WWTPs. The research in this study was conducted between 2009 and 2013, with the study timelines for the six WWTPs being: Beni-Messous (September 2009–June 2010), Tipaza (November 2010–June 2011), Boumerdes (January 2010–May 2011), Reghaia (April 2011–February 2012), Medea (November 2009–June 2012), and Kolea (September 2012–June 2013).

2.2. Sampling and analyses

A large part of the analyses was performed in accordance with French quality standards for organic amendments NFU44-095 [6] and NFU44-051 [7] at the laboratories of three agencies listed below, which managed the plant facilities and supervised the performance of wastewater treatment processes. The remaining analyses were carried out in the research laboratory of Water Sciences at the National Polytechnic Institute of Algiers. The analysis of the main agronomic parameters was carried out for the purpose of drawing a conclusion as to the expected impact due to the use of non-conventional resources.

(a) *ONA* (Office National d’Assainissement) at the Kolea, Boumerdes, Medea, and Tipaza WWTPs.
(b) *SEAAL* (Société des Eaux et de l’Assainissement d’Alger) at the Beni-Messous WWTP.
(c) *SARL* VaTech WABAG GmbH at the Reghaia WWTP.

3. Results and discussion

3.1. The soils

3.1.1. Soil composition

All the samples analyzed are representative of the silty clay composition of the Mitidja soils [8]. Granulometric analysis results indicate that the soils of the Mitidja region have high-clay content (49.3% on average), and high-fine silt content (29.4% on average), however, the coarse silt and sand contents were relatively low (Table 2).

The soils in this study are low in limestone, and neutral overall with some alkaline samples (maximum pH of 9.3) as a result of the predominance of Ca^{++} cations in the adsorbent complex (35.39 cmol(+)/kg of soil on average). The electrical conductivity (EC) factor measured indicates a lack of salinity, while the carbon dosage has shown quite low-OM rates. An average OM content of 1.3% and its minimum value of 0.2% indicate an urgent need to add OM to these soils. The cation exchange capacity (CEC), overall high

Table 1
Hydraulic characteristics of six WWTPs in North Central Algeria

	Beni-Messous	Boumerdes	Kolea	Medea	Reghaia	Tipaza
Volume (m^3/d)	50,400	15,000	11,000	15,000	80,000	11,200
Equivalent per capita	250,000	7,000	60,000	75,000	26,000	70,000

Table 2
Descriptive statistics of mineral constituents and soil densities

Parameters	Minimum	Maximum	Average	Standard deviation
Clay (%)	24	64	49.3	6.54
Fine silts (%)	17	47	29.4	6.90
Coarse silts (%)	3	14	6.5	2.86
Fine sands (%)	1	24	9.8	5.21
Coarse sands (%)	0	17	3.5	3.01
Real density	2.30	2.80	2.50	0.047
Apparent density	1.40	1.50	1.40	0.045

Source: (A. Habidi, 2007) [8].

(an average of 41.22 cmol(+)/kg of soil), is a result of the high rate of expansive clays, reaching 64% for some samples (Table 3).

3.1.2. Soil quality requirements for crops

- *Citrus fruits*: they grow on a variety of soils, including alluvial soils low in clay, clayey soils, as well as sandy soils. The pH for this crop is between 6.5 and 7.0.
- *Grape vines*: they fit a wide range of soils, but saline soils and those with high-limestone content are unfavorable. Grape vines prefer silty clay soils, with good structure and rich in OM. Their pH should be between 6.5 and 7.5.
- *Potatoes*: they prefer well drained silico-clay or clayey-siliceous soils. They also develop well in silico-calcareous soils. Heavy and compact soils do not suit this crop.
- *Tomatoes*: although they can be grown on all types of soil, tomatoes prefer siliceous clay or sandy clay, in deep and permeable soils. A pH between 5.6 and 6.8 is considered the best for this crop.
- *Chili peppers*: they prefer deep and well-drained soils for best yields. Heavy, clay soils are ruled

Table 3
Descriptive statistics of chemical and biological soil parameters

Parameters	Minimum	Maximum	Average	Standard deviation
$CaCO_3$ (%)	0.1	18.7	2.69	2.94
pH	5.82	9.30	7.03	0.85
EC (ds/m)	0.11	2.5	0.94	0.045
C (0/00)	0.23	15.9	6.72	3.59
N (0/00)	0.035	2.90	0.87	0.42
OM (%)	0.20	3.67	1.30	0.62
C/N ratio	1	11	7.9	2.16
Ca++	7.3	19	35.39	2.71
Mg++(cmoles/kg of soil)	0.30	2.45	4.55	0.42
Na+(cmoles/kg of soil)	0.14	2.45	0.70	0.32
K+(cmoles/kg of soil)	0.17	11	0.57	2.16
CEC(cmoles/kg of soil)	13.02	41.63	41.22	7.80

Note: Exchangeable alkalines in cmoles/kg of soil.

out. This crop develops better in alkaline soils, with an optimal pH between 6.5 and 7.0.

- *Chick peas*: they can be grown in different soil types, but prefer siliceous clay and heavy, deep, and well-drained silt textured soils. This crop dreads the calcareous soils, but behaves well on soils with slightly acidic (6) to alkali (9) pH. Chick peas are susceptible to poor soil aeration but tolerate salinity.
- *Barley*: it is an annual grass that adapts to all types of soil, with the exception of clayey soils, compact soils, and highly acidic soils. It slightly tolerates saline soils.
- *Wheat*: it prefers soils with siliceous or calcareous clay, rich in mineral and organic materials, capable of maintaining a water reserve sufficient to ensure proper nutrition.

The diversity of soils in North Central Algeria allows the adaptation of each culture in function of its needs. The distribution of soils by cultures places the citrus family (oranges, limes, lemons, grapefruit, etc.) ranked first, occupying 38% of the Mitidja croplands, followed by cereals with 27%, then arboriculture with 17%, vegetable farming with 11%, and finally grape vines with 6%. The hydromorphic factor is taken into account in the choice of crops and studied under limiting factors related to the general morphology [8] (Table 4).

3.1.3. Nutrient requirements for crops

The needs of plants Elements fertilizers are highly variable (Table 4).

- *Citrus fruits*: they have high-nitrogen requirements, ranging from 250 to 300 kg/ha.
- *Cereals*: they have moderate-nitrogen requirements, with 60–70 kg/ha for barley, and 90 kg/ha for wheat. The requirements of oats in fertilizers to be applied in September in favorable areas such as the coastline and the sublittoral Mitidja zones, is of 70 kg/ha of P_2O_5 and 50 kg/ha of K_2O. Oats have the lowest nitrogen requirements, with 46 kg/ha.
- *Arboriculture*: nitrogen requirements range from 130 to 160 kg/ha for the medlar, to 200 kg/ha for apples, pears, and quinces.
- *Vegetables*: they show highly variable nitrogen requirements ranging from 10 to 20 kg/ha (for lentils, feva beans, and peas) to 300 kg (for melons and watermelons), and 320 kg/ha (for tomatoes).
- *The grape vine*: its requirements are 140 kg/ha in nitrogen, 80 kg/ha in P_2O_5, and 100 kg/ha in K_2O.
- *Potatoes*: their requirements are 150 kg/ha in nitrogen, 120 kg/ha in P_2O_5, and 320 kg/ha in K_2O.
- *Peppers*: their requirements are 330 kg/ha in nitrogen, 80–100 kg/ha in P_2O_5, and 330 kg/ha in K_2O.
- *Cabbages*: their requirements are 130 kg/ha in nitrogen, 170 kg/ha in P_2O_5, and 110 kg/ha in K_2O.
- *Tender wheat*: its nitrogen requirement in sub-humid zones (rainfall greater than 450 mm/yr) is 92 kg/ha.

Sludge nitrogen production greatly exceeds the requirements of undemanding crops and fully covers those of moderately demanding plants [9]. Hydromorphic lands are generally reserved for vegetable farming, oriented towards industrial production such as canned tomatoes or species adapted to heavy soils, such as artichokes. For heavy soils with frequent congestion and no natural slope, the ideal crops are mostly vegetables adapted to heavy soils. For low hydromorphic soils, the proposed cultures are citrus fruits.

3.2. OM contribution

OM input in soils allows the increase in permeability and water balance, while playing a leading role in the assembly of soil aggregates [10]. It also helps to

Table 4
Fertilizer requirements for each type of crop (kg/ha)

	Citrus	Cereals	Arboriculture	Vegetable farming	Vine
Nitrogen	250–300	45–92	130–200	20–320	140
P_2O_5	100–120	45–92	120–180	70–120	80
K_2O	100–160	46–50	100–160	50–320	100

Source: (Fertial, 2011) [9].

retain significant mineralization in amended soil [11], with enrichment in mineral elements found within the first centimeters of the soil surface. Soils tend to have a neutral pH and are richer in phosphorus and OM [12]. OM content is variable and is dependent on the nature of the effluent. Sludge from the sewage of the Reghaia and Medea WWTPs has low OM contents, 34 and 28% of dry matter (DM), respectively, reflecting the influence of mineral industrial discharges which have not undergone treatment. These contents are similar to those reported by Robert and al Kolea WWTPs vary from 40.8 to 53.5% of DM, and are related to significant domestic and agri-food pollution [13] (Table 5).

OM quantities provided by sludge are significantly higher than those produced by urban compost, except for the Reghaia and Medea WWTPs, in which OM quantities remain comparable to the OM contents of compost (Table 5), and are therefore considered a positive factor for the life of the soil (Table 6). Concentrations of OM in sludge typically exceed those of compost.

3.3. The dryness effect

Sludge dryness is represented by an index used in the field of wastewater treatment. Sludge consists of water and solids; therefore, dryness is the mass percentage of DM, containing nutritive elements which can be reused in agriculture. The content of sludge in nutritive elements is therefore a function of the DM content. Sludge from the six WWTPs, in this study, show highly varied percentages of dryness from one plant to another, depending upon the dehydration technology being used (Table 7). These prove generally more efficient with good consistency and ease of shovellability. In fact, sludge treated soils retain moisture longer, with the root systems of vegetation grown on sludge treated soils being more developed compared to those grown on non-treated soils [16].

3.4. The C/N ratio

The C/N ratio is the indicator which is most utilized to characterize OM. Although this ratio is time dependent, it is not possible to predict the amount of stable carbon of an organic product [1]. The more the organic residues are rich in lignin, the more difficult their bio-degradation due to the recalcitrance of these plant polymers [2]. The results observed by LE Guillou [17] also confirm the negative relationship between decomposed organic residues and lignin content. This explains why the C/N ratio is higher for manure and compost, and rich in lignin, when compared to the C/N ratio of sewer sludge (Table 8).

Sewage sludge C/N ratio values vary from one WWTP to another depending upon the mass loading and the type of sludge stabilization. Indeed, for very low loadings, the residence time distribution increases while the highest oxygen consumption will result in

Table 5
Characteristics of sludge, cattle manure and urban compost

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza	Cattle manure [14]	Compost [15]
OM %	51	53.5	34	52	28	40.8	–	33
C % DM	22.6	31.10	21.6	32.3	15	16.2	–	15
N % DM	2.62	3.07	1.45	2.43	2.06	1.6	1.5	1.15
P_2O_5 % DM	5.62	2.60	2.2	6	0.33	0.22	0.8	1.05
K_2O % DM	0.048	0.07	0.05	0.043	0.19	0.074	1.35	1.1
C/N	8.65	10.13	14.89	12.8	7.32	10.12	16.45	13.15
Dryness %	51	17.46	35	41	44	48	–	–
pH	6.59	7.25	7.37	7.36	7.25	7.74	–	–
CaO %	3.68	5.07	–	6.2	–	1.85	1.1	5.75
MgO %	–	1.66	1.2	0.56	–	0.95	6.1	0.745

Table 6
Comparison of sludge OM contents with those of compost

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
OM (%DM) in sludge	51	53.5	34	52	28	40.8
OM (%DM) in compost [10]	33	33	33	33	33	33

Note: Concentrations of OM in sludge typically exceed those of compost.

Table 7
Representation of sludge dryness at six WWTPs in North Central Algeria

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
% of Sludge dryness	51	45	35	41	44	48

Note: The dryness of the sludge varies from one WWTP to another.

Table 8
Representation of C/N ratios of sludge, compost, and cattle manure

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
C/N of sludge	8.5	10.13	14.89	12.8	7.32	10.12
C/N of cattle manure [14]	16.45	16.45	16.45	16.45	16.45	16.45
C/N of compost [15]	13.15	13.15	13.15	13.15	13.15	13.15

greater mineralization with a low C/N ratio. In contrast to an average mass loading of 0.25 kg BOD5/kg MVS/d at the Reghaia WWTP, and a chemical sludge stabilization with lime milk, the C/N ratio of the sludge remained quite high. Based on classification proposed by Chaussod et al. [18], sludge from the sewage of Beni-Messous, Boumerdes, Medea, and Tipaza, with C/N ratios varying from 6 to 12, release 30–40% of nitrogen, shortly after their spreading, thereby making the nutrients quickly available. In order to avoid sludge leaching due to the low values of the C/N ratio, sludge should be applied during periods of plant growth. However, the Reghaia and Kolea WWTPs, with a C/N ratio greater than 12, produce sludge which can cause a temporary blockage of nitrogen due to insufficient stabilization, leaving an excess of readily fermentable carbon. Sludge from the Reghaia WWTP, nitrogen deficient (1.45 N % DM), with a C/N ratio of 14.89 just at the limit proposed by Grimaud [19], evolve little and may prolong the immobilization of soil nitrogen (Table 9).

3.5. Maximum Quantities of Sludge to Spread

3.5.1. Trace metal elements

The tables below show average trace metal elements (TME) content in sludge collected from the six WWTPs selected in this study compared to the (mg/kg DM) limit values of the NFU 44-051 [7] quality standards.

Copper content in sludge exceed those of cattle manure (except in Boumerdes, where copper content remain below those in manure), and all six WWTPs

Table 9
Influence of the type of sludge treatment on the value of the C/N ratio

	C/N ratio	Mass loading	Sludge treatment
Beni-Messous	8.65	Very low-mass loading, $C_m = 0.075$ kg DBO_5/kgMVS/d	Thickening, aerobic stabilization, mechanical dehydration
Boumerdes	10.13	Very low-mass loading, $C_m = 0.076$ kg DBO_5/kgMVS/d	Static thickening, mechanical dehydration, landfill
Reghaia	14.89	Average loading, $C_m = 0.25$ kg DBO_5/kg MVS/d	Thickening, chemical stabilization (milk of lime) and then dehydration by centrifugation
Kolea	12.8	Low-mass loading, $C_m = 0.098$ kg DBO_5/kgMVS/d	Thickening + dehydratation + drying + discharge
Medea	7.32	Very low-mass loading, $C_m = 0.070$ kg DBO_5/kgMVS/d	Thickening, aerobic stabilization, drying bed
Tipaza	10.12	Active sludge with low-mass loading, $C_m = 0.081$ kg DBO_5/kgMVS/d	Thickening, mechanical dehydration, landfill

remain below the NFU 44-051 limit value [7] (Table 10).

For the Beni-Messous, Boumerdes, and Kolea WWTPs, average mercury content in sludge are lower than those of cattle manure and represent only 5–12% of the NF U44-051 limit value [7] (Table 11).

For all six WWTPs, zinc contents in sludge exceed those of cattle manure and remain below the NF U44-051 limit value [7] (Table 12).

There is a wide range of lead content from one WWTP to another. Sludge obtained from the Beni-Messous WWTP contains lead exceeding the NFU 44-051 limit value, while Kolea and Reghaia are below the contents recorded for cattle manure, and remain far below the NFU 44-051 limit value [7]. Chromium content in sludge is highly variable from one WWTP to another, depending on the relation to industrial pollution specific to each site. For example, the chromium content of the Reghaia WWTP exceeds the NF U44-051 limit value [7], due to the discharges in hexavalent chromium from a nearby industrial complex of heavy vehicle assembly (Table 13).

For Beni-Messous, the average nickel content in sludge exceeds the NFU 44-051 limit value [7], but for the Reghaia and Medea WWTPs, nickel content remain lower than those of cattle manure (Table 14).

Cadmium content in sludge at the Boumerdes and Beni-Messous WWTPs exceeds the NFU 44-051 limit value [7]. The cadmium content of the remaining four WWTPs is comparable to those of farmyard manure (Table 15).

Average quantities of (Cr + Cu + Ni + Zinc) in sludge are below the NFU 44-051 limit value [7]. The content at the Medea and Reghaia WWTPs are even lower than the content of these metals in cattle manure (Table 16).

For all stations, the average concentrations (Cr + Cu + Ni + Zinc) sludge are lower than those imposed by the standard NF U44-051. [7] The average concentrations of these metals are present in the cattle manure (Table 17).

Table 10
Average copper quantities in sludge compared with those of copper in cattle manure and the NF U44-051 limit value (mg/kg of DM) [7]

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
Copper in sludge (mg/kg DM)	173.8	70	2.11	157	41.96	99.2
Cattle manure in sludge (min) [20]	5	5	5	5	5	5
Cattle manure in sludge (max) [20]	40	40	40	40	40	40
NFU 44-051 [7]	300	300	300	300	300	300

Table 11
Average quantities of mercury in sludge compared with those of mercury in cattle manure and the NF U44-051 limit value (mg/kg of DM) [7]

	Beni-Messous	Boumerdes	Kolea
Mercury in sludge (mg/kg DM)	0.24	0.1	0.21
Mercury in cattle manure (max) [20]	0.6	0.6	0.6
Mercury in cattle manure (max) [20]	2	2	2

Table 12
Average quantities of zinc in sludge compared with those of zinc in cattle manure and the NF U44-051 limit value (mg/kg of DM) [7]

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
Zinc in sludge (mg/kg DM)	580	510	132.28	526.9	217	526.9
Zinc in cattle manure (min) [20]	75	75	75	75	75	75
Zinc in cattle manure (max) [20]	500	500	500	500	500	500
NFU 44-051 [7]	600	600	600	600	600	600

Table 13
Average quantities of lead in sludge compared with those of lead in cattle manure and the NF U44-051 limit value (mg/kg of DM) [7]

	Beni-Messous	Boumerdes	Kolea	Reghaia
Lead in sludge (mg/kg DM)	226.16	130	20	3.528
Lead in cattle manure (min) [20]	5	5	5	5
Lead in cattle manure (max) [20]	90	90	90	90
NFU 44-051 [7]	180	180	180	180

Table 14
Average quantities of chromium in sludge compared with chromium in cattle manure, compared to the NF U44-051 limit value (mg/kg of DM) [7]

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
Chromium in sludge (mg/kg DM)	58.81	120	136.71	40.26	10.96	41.6
Chromium in cattle manure (min) [20]	5	5	5	5	5	5
Chromium in cattle manure (max) [20]	60	60	60	60	60	60
NFU 44-051 [7]	120	120	120	120	120	120

Table 15
Average nickel quantities in sludge compared with those of nickel in cattle manure and the NFU 44-051 limit value (mg/kg of DM) [7]

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
Nickel in sludge (mg/kg DM)	78.24	50	1.54	27.4	12.13	25.26
Nickel in cattle manure (min) [20]	6	6	6	6	6	6
Nickel in cattle manure (max) [20]	40	40	40	40	40	40
NFU 44-051 [7]	60	60	60	60	60	60

Table 16
Average cadmium quantities in sludge compared with cadmium in cattle manure and the NF U44-051 limit value (mg/kg of DM) [7]

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
Cadmium in sludge (mg/kg DM)	6.38	5	0.142	1.6	0.57	1.3
Cadmium in cattle manure (min) [20]	0.3	0.3	0.3	0.3	0.3	0.3
Cadmium in cattle manure (max) [20]	1.5	1.5	1.5	1.5	1.5	1.5
NFU 44-051 [7]	3	3	3	3	3	3

Table 17
(Cr + Cu + Ni + Zn) Contents in sludge compared with those of cattle manure and the NF U44-051 limit value (mg/kg of DM) [7]

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
Cr + Cu + Ni + Zn in sludge (mg/kg DM)	890	725	273	1,191	282	728
Cr + Cu + Ni + Zn in cattle manure [20]	1,080	1,080	1,080	1,080	1,080	1,080
NFU 44-051 [7]	640	640	640	640	640	640

- *WWTP of Reghaia*
  - The NFU standard 44-051 [7] limit value for chromium is 16 T/ha/yr, with a spreading of the quantities produced over a period of 10 years not exceeding 43 T/ha.
- *WWTP of Boumerdes*
  - The limit value for cadmium is 9 kg/ha/yr, with maximum use of 30 T/ha over a period of 10 years.
- *WWTP of Tipaza*
  - The sludge from the sewage of Tipaza allow application of 17 T/ha/yr of zinc, not exceeding 56 T over a period of 10 years. Regarding copper, the limit value is 31 T/ha/yr, with a spreading not exceeding 103 T/ha over a period of 10 years.
- *WWTP of Beni-Messous*
  - The limit value for nickel is 11.5 T/ha/yr, not exceeding 38 T/ha over a period of 10 years.
  - With regard to lead, the limit value is approximately 12 T/ha/yr, not exceeding 40 T/ha over a period of 10 years.
  - The zinc allows spreading of about 15 T/ha/yr with 51 T/ha over a period of 10 years.
  - The limit value for cadmium is 7 T/ha/yr, with a spreading not exceeding 23 T/ha. Cadmium is the limiting factor the most restrictive for agricultural use of sludge from the Beni-Messous WWTP.

3.5.1.1. Toxicity. The effects of heavy metals influence the growth, morphology, and metabolism of telluric micro-organisms by protein denaturation or destruction of the integrity of the cell membrane [21]. Due to contamination by metals, many studies show that there is a decrease in the bacterial biomass of soils [22–24]. Moreover, Giller et al. [25] report that, even in the long term, and even for very low-heavy metal content, micro-organisms are not able to maintain biomass equivalent to those of non-contaminated soils.

3.5.2. Organic trace compounds

Similar to TME contents, organic trace compound (OTC) contents were measured in the sludge obtained from the Beni Messous WWTP and compared to the NFU 44-095 [6] and NFU 44-051 [7] limit values. These reference values and the OTC contents of Beni Messous sludge are shown in Table 18, which shows the contents of organic trace compounds in sludge (mg/kg DM). For a sludge spreading of 10 T/ha, the contents of Fluoranthene, Benzo (b) fluoranthene, and Benzo (a) pyrene are very low relative to the values limiting the use of sewage sludge in agriculture, and are therefore no threat to this type of valorisation. For a 10 T/ha spreading of Beni Messous sludge, the input of 7 PCBs is 5.4 g/ha, a value which is almost four times the NFU44-095 standard limit value for a 10 year period [6]. The 7 PCBs content constitute the limiting factor for the Beni Messous WWTP sludge used for agriculture (Table 19).

3.6. Contribution of sludge nutrients

Sludge contains significant quantities of OM and nutrients. The calculation of the maximum spreadable surfaces per hectare is made by considering the dose limits imposed by the concentrations of heavy metals in the sludge from each WWTP. Some experiments have shown that an improvement of permeability and structural stability would be achieved after an intake of 10 T/ha of sludge DM for several years [26]. To achieve this goal, potential surfaces for spreading of 10 T/ha/yr were calculated for the Medea, Reghaia, and Tipaza WWTPs, not to exceed the limits imposed for the other WWTPs. This approach must also take

Table 18
Contents of heavy metals in excess compared with NFU 44-051 quality standards

	Cadmium	Chromium	Copper	Nickel	Lead	Zinc
Reghaia (g/ha)	–	547	–	–	–	–
Beni-Messous (g/ha)	25.52	–	–	313	905	2,320
Tipaza (g/ha)	–	–	397	–	–	2,108
Boumerdes (g/ha)	20	–	–	–	–	–
NFU44-051 (mg/ kg DM) [7]	3	120	300	60	180	600
NFU44-051 (g/ha/Spreading) [7]	45	1,800	3,000	900	2,700	9,000
NFU44-051 (g/ha/10 yr) [7]	150	6,000	10,000	3,000	9,000	30,000

Table 19
Contents of OTCs in the Beni-Messous sludge

	Average (mg/kg DM)	Average for 10 T/ha of sludge (g/ha)	NFU 44-051 [7] spreadig (g/ha)	NFU44-51 [2]/NFU44-095 [6] (g/ha/10 years)	NFU44-095 [6] (mg/kg DM)	NFU44-051 [7] (mg/kg DM)
Sum of 7 PCBs	0.54	5.4	–	1.2	0.8	–
Fluoranthene	0.09	0.9	6	60	4	4
Benzo(b) fluoranthene	0.09	0.9	4	40	2.5	2.5
Benzo(a) pyrene	0.09	0.9	2	20	1.5	1.5

into account the restrictions related to the presence of heavy metals and organic trace elements for a 10 year period. On average, an individual generates 200 litres of wastewater per day, which once processed, produces five litres of raw sludge containing close to 15 g of DM. Potentially, the six WWTPs can globally produce 5,221 tons of sludge, to meet the OM requirements of about 320 ha of cropland, with a 10 T/ha/yr dose of sludge for the Tipaza, Reghaia, and Medea WWTPs. At Beni-Messous, Boumerdes, and Kolea, the dose limits are 7, 9 and 6 T/ha of sludge per year, respectively, with the total area to be spread being 280 ha, for a total of 600 ha. If 17 ha is subtracted from the Medea WWTP (located to the South of the Mitidja), the sludge in the Mitidja region will cover an area of 583 ha. This represents approximately just 0.50% of the 120,000 ha of the total agricultural area of the Mitidja region.

Table 20 shows that a spreading of sludge produces large quantities of nitrogen and phosphorus, but very little potassium.

3.6.1. Nitrogen

Nitrogen contents in sludge exceed those of manure and compost, except for Reghaia and Tipaza WWTPs, where nitrogen values remain comparable to those of manure and compost (Table 22).

Spreading 10 T/ha of sludge provides quantities of nitrogen ranging between 105 and 307 kg/ha, greatly exceeding those produced by farm manure and compost, except for the Reghaia and Tipaza WWTPs, where values remain comparable to those of manure and compost (Table 21). This can be explained by the fact that compost or farmyard manure last long after maturation, and are more likely to suffer losses in nitrogen, particularly by the nitrification/denitrification phenomenon. Solubilization of this wealth in nitrogen is related primarily to the high dryness of sludge, limiting increased losses in nitrogen (Table 22).

3.6.2. Phosphorus

According to Ratel et al. [29], the phosphorus requirements of agricultural plants vary from 30 to 80 kg/ha. Table 23 shows that a 10 T/ha dose of sewage sludge produces a significant amount of phosphorus.

Table 24 shows the quantities of phosphorus produced by the spreading of 10 T/ha of sludge far exceeds those produced by compost and manure. Sludge phosphorus intake varies from 220 kg/ha

Table 20
Sludge quantities produced, and surfaces potentially spreadable with a 10 T/ha/yr spreading rate

	Equiv./ Inhab.	Volume (water) m^3/d	Volume (water) m^3/yr	Tons of sludge/ yr	Limit doses T/ ha/yr	Maximum surfaces allowed for spreading (ha)	Potential surfaces for the spreading of 10 T/ha (ha)
Tipaza	70,000	11,200	4,088 000	306	17	18	31
Beni-Messous	250,000	50,400	18,396 000	1,380	7	197	197
Reghaia	263,000	80,000	29,200 000	2,190	16	136	219
Boumerdes	75,000	15,000	5,475 000	410	9	45	45
Medea	162,000	26,000	9,490 000	711	41	17	71
Kolea	58,000	8,200	2,993 000	224	6	37	37
Total	–	–	–	5,221	–	450	600

Table 21
Quantities of fertilizers and OM produced by sludge in applications with respect to the dose limits for each WWTP

	Limit doses (T/ha/yr) **sludge**	OM (T/ha)	Total nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)	Calcium (kg/ha)	Magnesium (kg/ha)
Beni-Messous	7	3.57	183	393	3.36	257	–
Boumerdes	**9**	4.81	276	234	6.3	454	148
Reghaia	**16**	5.44	232	352	8	–	192
Koléa	**6**	3.12	145.8	360	2.55	372	33
Medea	**41**	11.48	844	2,706	77.9	–	–
Tipaza	**17**	6.92	272	–	12.32	314.5	161.5
Cattle Manure G. Hainnaux [14]	**10**	–	150	80	135	110	610
Manure [27]	10	4.1	150	10	160	10	2
Compost [28]	10	2.7	110	11	110	12	2
Compost Matejka et al. [15]	10	3.3	115	105	110	575	75

Note: Contributions in OM and fertilizers compost and manure correspond to a spreading 10 T/ha.

(Reghaia WWTP) to 660 kg/ha (Medea WWTP), 562 kg/ha (Beni-Messous WWTP), 260 kg/ha (Boumerdes WWTP), and 600 kg/ha (Kolea WWTP).

3.6.3. Potassium

Potassium content in sludge is low when compared to those of urban compost and manure (Table 25). It is soluble and can be easily eliminated from sludge [30]. The values in Table 25 are in agreement with those proposed by Brame and Lefevre [31]. The spreading of high doses of sludge, therefore, does not exempt the farmer from using potassium as fertilizer.

3.6.4. Calcium

Sewage sludge contains calcium in significant quantities, ranging from 1.85 to 6.2% of CaO in DM from one WWTP, to another. These values are similar to those reported in Anred [32] and are in agreement with Hurt [33], who argues that a sludge injection increases the content of calcium in the soil. Calcium contents greatly exceed those of farmyard manure, as they remain comparable to those of urban compost (Table 5). This can be explained in part, by the increase in calcium concentration resulting from the decrease in sewage sludge that occurs as a result of OM oxidation. The effect of CaO input is significant at a dose of 10 T/ha of sludge, which can reach up to

Table 22
Nitrogen contents of sludge, compost, and manure

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
Nitrogen in sludge (%DM)	2.619	3.07	1.45	2.43	2.06	1.6
Nitrogen in cattle manure [28]	1.5	1.5	1.5	1.5	1.5	1.5
Nitrogen in compost [31]	1.15	1.15	1.15	1.15	1.15	1.15

Table 23
Nitrogen quantities produced by sludge manure and compost with a spreading of 10 T/ha

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
Nitrogen in sludge (kg/ha)	105	307.5	145	243.5	206.5	160
Nitrogen in cattle manure [28]	150	150	150	150	150	150
Nitrogen in compost [31]	115	115	115	115	115	115

Table 24
Maximum and minimum phosphorus quantities in sludge compared with those produced by other products at 10 T/ha

	Beni Messous	Boumerdes	Reghaia	Kolea	Medea
Phosphorus in sludge (kg/ha)	562	260	220	600	660
Phosphorus in cattle manure [14]	80	80	80	80	80
Phosphorus in compost [15]	105	105	105	105	105
Phosphorus upper limit [29]	200	200	200	200	200
Phosphorus lower limit [29]	75	75	75	75	75

Table 25
K_2O quantities produced by sludge, manure, and compost with a spreading of 10 T/ha

	Beni-Messous	Boumerdes	Reghaia	Kolea	Medea	Tipaza
K_2O in sludge (kg/ha)	1.92	7	5	4.25	19	7.25
K_2O in Cattle Manure [14]	135	135	135	135	135	135
K_2O in compost [15]	135	135	135	135	135	135

Table 26
Comparison of TME content in fertilizers, cattle manure, and sewage sludge

WWTP	Cadmium	Chromium	Copper	Nickel	Lead	Zinc	Mercury	Cr + Cu + Ni + Zn
Medea	0.57	10.96	41.96	12.13	–	217	–	282
Reghaia	0.142	136.71	2.11	1.542	3.528	132.28	–	272.64
Beni-Messous	6.38	58.81	173.8	78.24	226.16	580	0.24	890.85
Koléa	1.6	40.26	157	27.4	20	967	0.21	1191.6
Tipaza	1.3	41.6	99.20	25.26	–	526.90	–	728.52
Boumerdes	5	120	70	50	130	510	0.1	725.26
Nitrogen fertilizer [20]	0–10	6–10	5–10	1–10	0.5–10	2–10	0–1	40
Phosphatic fertilizer [20]	9–100	90–1,500	10–60	5–70	0.5–40	50–600	0–0.2	2,230
Potassium fertilizer [20]	0.1–2	0.1–15	0.1–10	0.1–3	5–15	1.15	0–0.2	43
Cattle manure [14]	0.3–1.5	5–60	5–40	6–40	5–90	75–500	0.1–0.6	640
NFU 44-051 [7] (mg/kg DM)	3	120	300	60	180	600	2	1,080

505 kg/ha for the Boumerdes WWTP and up to 620 kg/ha for the Kolea WWTP. The CaO input increases the content of calcium in the soil and controls its acidity [33].

3.6.5. Magnesium

Magnesium content in sludge range from 0.56 to 1.66% of DM, and remain comparable to those proposed by Impens and Avril [34], which indicate that magnesium salts are highly soluble, and therefore easily disposable. Furthermore, magnesium content tends to be much lower than those of farm manure but higher than those of urban compost (Table 5). At a dose of 10 T/ha of sewage sludge, the effect of magnesium input is small, with values ranging from 55 kg/ha for the Kolea WWTP and up to 165 kg/ha for Boumerdes.

3.7. Effect of TME

The presence of heavy metals in sewage sludge is a major obstacle to its utilization in agriculture. Sludge contains between 70 and 90% of the TME quantities in sewage wastewater entering the WWTPs [20]. Table 26 shows results made on a number of fertilizers widely utilized in agriculture. Even if the TME contents vary depending on their origins, types, and manufacturers [21], none of these products are free from traces of undesirable elements. On a practical level, this information suggests that a rigorous evaluation of TME flows to the soil must take into account all possible sources. Some of the studies undertaken in this sense [21] have shown that heavy-metal elements, such as Pb and Hg, are strongly retained in the adsorbent phase, and are therefore not sufficiently available for plants. In general, Zn and Ni are relatively soluble in various chemical reactives, are quite mobile in soils, and are easily absorbed by plants. Brame and Lefevre [31] reported that heavy-metal toxicity manifests itself particularly in acid soils, but the basic pH of sludge tends to maintain heavy metals adsorbed by the clay, compounded by OM and the hydroxide composites of the soil. This inner action of soils makes the determination of threshold limit values for heavy metals very difficult.

3.8. The microbiological risk for soil and vegetation

The major diseases transmitted by effluents are: schistosomiasis, hookworm, roundworm, toeniadysenterie, cholera, bacillary dysentery, poliomyelitis, and infectious hepatitis. Most sludge treatments against these diseases result in a drop of pathogen populations, but they very rarely completely disappear. It can be concluded that sludge, even after stabilization, should not be delivered in direct contact with vegetation, which would likely be consumed raw. There is long standing evidence that pathogenic micro-organisms cannot penetrate or survive internally within the plants. The micro-organisms are therefore found on the surface of plants and soil. There may therefore be contamination during plant growth or harvest. Pathogens survive over long periods of time on the soil surface and on plants [35].

4. Conclusions

The analysis of sludge obtained from six WWTPs in the Mitidja region of Algeria shows that in addition to OM, sludge provides a great contribution to fertilizers. In fact, sludge provides most of the nutrients required by the plants, with the exception of potassium. In addition, this study shows that the contents of nutrients from sewage sludge are quite variable from one WWTP to another. It is important to base the agronomic recommendations with precise analysis, rather than on the average contents of nutrients contained in the sludge. This study also indicates that with low-mass loading values, the C/N ratio in sludge treatment is always less than 20, which makes the risks of blockage of mineral nitrogen in soils minimal. The sludge produced in the six WWTPs will cover an area of 583 ha. This represents approximately just 0.50% of the 120,000 ha of the total Mitidja agricultural area.

OM content produced by sludge, generally, exceed those made by urban compost, however, the soil in the Mitidja region is very poor in OM with an average value of only 1.3% and a minimum value of 0.2%. The total production of sludge remains very low and covers only 0.83% of the agricultural area of the Mitidja region with a spreading rate of 10 T/ha/yr. The use of an alternate source of organic enrichment such as urban compost is therefore essential. Indeed, waste composition in the Mitidja region is very favorable to this kind of practice (high-moisture content, high-OM content, and low LHV (lower heating value). To compensate for OM deficit, using sludge mixed with urban compost or farmyard manure is recommended. The proportions should be calculated on the basis of the composition of each product, taking into account the criteria of environmental pollution control and soil and plant requirements of OM and nutrients. This will allow for the achievement of a more balanced and better adapted formula under an organic soil amendment framework where humus plays an essential role in soil fertility in a perspective of respect for the environment.

The comparative study of sludge with other fertilizer products indicates that none of these products is free from undesirable trace elements. The evaluation of trace metals flowing to the ground must carefully take into account all possible sources of these trace elements. The constraints on agricultural reuse of sludge are mostly related to the high acidity of the soil and to its low thickness, which accentuates the possibilities of leakage of potentially toxic elements into underground waters. The alkalinity of sludge pH has the advantage of limiting the risk of toxicity due to TME. Lastly, in order to restore the stock of humus in soils, it is essential to implement a policy of awareness, information, and promotion with soil managers in order to increase the consciousness for the urgent need of better management of OM, from production to utilization.

Acknowledgments

This work was conducted in the Research Laboratory of Water Sciences at the National Polytechnic Institute of Algiers, in collaboration with the laboratories of three agencies listed below. The authors would like to thank and acknowledge the support of these agencies which facilitated access to their documentation as well as to the analytical data of the parameters required for this study.

(1) *ONA* (Office National d'Assainissement) at the Kolea, Boumerdes, Medea, and Tipaza WWTPs.
(2) *SEAAL* (Société des Eaux et de l'Assainissement d'Alger) at the Beni-Messous WWTP.
(3) SARL VaTech WABAG GmbH at the Reghaia WWTP.

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