https://erjm.journals.ekb.eg
ISSN:

DOI: ---------

ERJ
Engineering Research Journal
Faculty of Engineering
Menoufia University

Dewaterability and Stabilisation of Municipal Sludge from Egyptian Waste Water Treatment Plants Using Constructed Wetland

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ABSTRACT

The amounts of sludge increased rapidly in recent years with increase the population growth as a result rapid urbanization, lack of capacity, planning and financing for the establish of the sewage network. Sludge is the largest source of pollution in many countries around the world. This problem increases with the treatment of sewage from developing countries. Constructed wetlands have been used as a green technology to sewage sludge treatment. The main aim of this study was sludge dewatering and stabilisation to evaluate the quality of the final product which can be used in agriculture. Sewage sludge was treated by different types of plants (millet, cowpea, Sudan grass, alfalfa, oat and barley) through summer and winter seasons by irrigation using fresh water and treated wastewater. Millet plant had the highest value of elements by irrigation using fresh water and treated waste water in summer season. In winter, oat plant had the highest value of elements by irrigation using fresh water and alfalfa plant by irrigation using treated waste water. This technology is little used at present. Therefore, further research is required to provide sustainable solutions for constructed wetlands in Egypt.

Keywords: *sludge; sewage sludge; sewage treatment; wastewater; Soil; Egypt*

1. Introduction

Sewage sludge management is a critical environmental issue and one of the most expensive processes in municipal wastewater treatment. Increasing sludge production has required the development of alternative treatment technologies with the goal to reduce sludge volume, organic matter, microbiological and heavy metal content as well as the content of several emerging toxic contaminants [1, 2].
The main methods for sludge disposal have been and still are landfill, agricultural use and incineration, all incurring very large costs [3]. Therefore, reducing sludge production in WWTPs has become an important topic for both practitioners and researchers. In the sludge treatment line, sludge is subject to thickening, stabilization, dewatering and final disposal. Anaerobic digestion is the most commonly used sludge stabilization method, which is used to reduce the mass of sludge [4].
Sludge treatment wetlands (STWs) are considered as a sustainable technology for sludge management from both an economical and environmental point of view [5]. STWs are also known as sludge drying reed beds, it is rather new sludge treatment systems [6] and are made up of shallow ponds, beds or trenches filled with a gravel layer and planted with emergent rooted wetland vegetation such as Phragmites australis [7]. Therefore, wetland vegetation is a very important and prime component of a wetland ecosystem [8]. The systems are termed green technology.
Wastewater treatment plants in the Arab Republic of Egypt produce quantities huge of sludge annually estimated with (4 million tons per year almost) these huge quantities must be used or disposed of in a safe way. There-fore, this study focuses on discussing these important issues related to sewage sludge of using vegetated wetland, which are useful in sustaining soil quality and agricultural productivity in Egypt.

2. Materials and Methods

2.1 Study Area

The study was conducted in Egypt, in the city of Kafr Shukr (a village Kafr El-Shahawi Khater), Qalyubia Governorate. The climate is classified a semi-desert, which is hot in the summer and moderate in the winter, with average annual temperature of 25 °C, the average annual wind speed and relative humidity are 0.23 m/sec and 59.9 % respectively.

2.2 Process description

The tested methods of the wetted and dried sludge were:

• Sludge with green fodder
• Sludge with grass

Irrigation is used regularly especially in the first weeks of the plant's development. Fresh water and treated wastewater are used, as shown in Figure (1). The sludge produced from Kafr El-Shahawi Khater Sewage Treatment Plant (STP) was used in cultivating the selected plants.

The sludge product produced by the process in the period from April to September 2018 in summer season and from November to mid-March 2019 in winter season was analyzed according to its chemical-physical characteristics.

Figure 1- (a) Fresh water; (b) Treated wastewater from the Chlorine basin

2.3 Plants

2.3.1 Pearl Millet

Millets [9] are a group of small-seeded grasses and it's grown around the world as cereal crops or grains for fodder and human food. The most widely grown millet is pearl millet and it is an important crop in India and parts of Africa.[10] Pearl millet is well adapted to growing areas characterized by drought, low soil fertility and high temperature and it is a summer annual crop well-suited for growing crops.[11] as shown in Figure (2).

2.3.2 Cowpea

Cowpea (Vigna unguiculata) is one of the most popular grain legumes in Africa as well as in some regions of America and Asia; it's highly valuable as food and feed for livestock. [12] as shown in Figure (3).

Figure 2- Millet plant (water and treated)

Figure 3- Cowpea plant (water and treated)

2.3.3 Sudan grass

Sudan grass (Sorghum vulgare var. Sudanese) is an annual summer plant that fits well in short rotations and it is tolerant of drought and warm temperatures [13]. Sudan grass grows wild in the Nile Valley of Africa. It is cultivated in Western Europe, North and East Africa, India, North America (USA), South America and Australia. In the USSR the plant is cultivated for forage. [14] as shown in Figure (4).

2.3.4 Alfalfa

Alfalfa (Medicago sativa), it is a perennial plant in the legume (family Fabaceae), it is cultivated as an important forage crop in many countries around the world and it is used for grazing, hay, and silage as well as a green manure and cover crop. [15] as shown in Figure (5).

Figure 4- Sudan grass plant (treated and water)

Figure 5- Alfalfa plant (water and treated)

2.3.5 Oat

The oat (Avena sativa), sometimes called the common oat [16, 17], is a species of cereal / grain grown for its seed [18-20]. While oats are suitable for human consumption as oatmeal and one of the most common uses is as livestock feed [21,22]. Oat forage is used for ruminants feeding such as pasture, straw, hay or silage [23] as shown in Figure (6).

2.3.6 Barley

Barley (Hordeum vulgare), a member of the grass family and it is a major cereal / grain grown in temperate climates globally. Barley has been used as animal fodder and as a component of various health foods. In 2017, barley was ranked fourth among grains after maize, rice and wheat. [24] as shown in Figure (7).

Figure 6- Oat plant (water and treated)

Figure 7- Barley plant (treated and water)

2.4 Analyses

Samples were analyzed for Raw sludge, Physical, chemical, biological analysis, Heavy metals and wet and dry sludge in soil, water and plants. Water samples were measured directly, while soil and plants samples were measured using drying, digestion (Acid Digestion in a Mixture of H_2SO_4 and 30% H_2O_2) according to Standard Methods for Examination of Water and Waste water [25] and Methods of Soil Analysis [26].

Physico-chemical parameters were measured pH using pH meter, Electrical Conductivity (EC) Using Conductivity Meter, Total and Volatile Solids (TS and VS), Chemical Oxygen Demand (COD), Total Kjehldahl Nitrogen (TKN) using digestion and distillation apparatus (Micro-Kjehldahl), Total Phosphorus (TP) by Spectrophotometer and heavy metals (mercury, lead, copper, cadmium, chromium,) using Atomic Absorption Spectrometer, while biological parameters were measured total coliform and fecal coliform in raw sludge during the experiment. All the analysis were carried out according to Standard Methods for the Examination of Water and Wastewater [25].

Heavy metals of plants: The elemental concentration in plant tissue is expressed on the basis of the dry weight of the macronutrients (N, P, K, Mg and Ca) expressed as a percentage; the concentration is to the nearest 0.01% and the micronutrients (Cu, Fe, Mn and Zn) expressed as either milligram per kilogram mg/kg. Heavy metal concentration is determined by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP).

3. Results and Discussion

3.1 Raw sludge characteristics

Faecal bacteria indicators of 7 raws sludge samples, trace metals and physico-chemical parameters were analyzed according to the results Table (1) to characterize the sludge used in the experiment.

Table 1- Average raw sludge samples characteristics

Trace Metals			Physico-chemical parameters		
Al		0.252	PH	-----	7.51
Sb		<0.009	CO_3		0
As		<0.002	HCO_3		555
Ba		<0.049	Total Alkalinity	(mg/l)	555
Cd		<0.002	TDS		949
Cr		<0.002	T. P		3.54
Co		0.003	T. N		38.00
Cu	(mg/l)	0.017	EC	(mmhos/cm)	1.48
Fe		0.380	Major Cations		
Pb		<0.007	Ca		54.94
Mn		0.185	K	(mg/l)	26.50
Ni		0.009	Mg		18.27
Se		<0.007	Na		142.50
Sn		<0.006	Concentration of faecal bacteria indicators		
V		<0.001	Total Coliform		1330×10^4
Zn		0.0215	Faecal Coliform		290×10^4

3.2 Summer agriculture

3.2.1 Pearl Millet Plant

Table (2) showed that the lowest values of nitrogen, magnesium and calcium are 1.71 (%), 0.122 (%) and 0.209 (%) respectively, while the highest values of phosphorus and potassium are 0.338 (%) and 1.622 (%) respectively. The highest values of copper, cadmium, cobalt, manganese, nickel and iron are 32.95 mg/kg,3.102 mg/kg,3.295 mg/kg,45.90 mg/kg,0.701 mg/kg and 8.44 mg/kg respectively, while the lowest values of lead, chromium and zinc are 23.04 mg/kg,55.47 mg/kg and 47.57 mg/kg respectively with millet plant if compared with the treated wastewater.

3.2.2 Cowpea Plant

Table (2) showed that the lowest values of nitrogen, potassium and calcium are 1.62 (%), 0.167 (%) and 0.124 (%) respectively, while the highest values of phosphorus and magnesium are 0.300 (%) and 0.139 (%) respectively. The highest values of copper, chromium, cadmium, cobalt, zinc, manganese and nickel are 33.02 mg/kg,69.58 mg/kg,3.165 mg/kg,3.414 mg/kg,55.32 mg/kg,32.46 mg/kg and 0.673 mg/kg respectively, while the lowest values of lead and iron are 22.99 mg/kg and 4.86 mg/kg respectively with cowpea plant if compared with the treated wastewater.

3.2.3 Sudan grass Plant

Table (2) showed that the lowest values of nitrogen and potassium are 1.74 (%) and 2.530 (%) respectively, while the highest values of phosphorus, magnesium and calcium are 0.291 (%), 0.079 (%) and 0.335 (%) respectively. The lowest values of copper, lead, nickel and iron are 30.29 mg/kg,22.92 mg/kg,0.372 mg/kg and 4.86 mg/kg respectively, while the highest values of chromium, cadmium, cobalt, zinc and manganese are 93.85 mg/kg,0.485 mg/kg,0.506 mg/kg,55.32 mg/kg and 40.74 mg/kg respectively with Sudan grass plant if compared with the treated wastewater.

3.3 Winter agriculture

3.3.1 Alfalfa Plant

The results showed that the highest values of nitrogen, potassium and calcium are 8.573 (%), 286.40 (%) and 0.003 (%) respectively, while the lowest values of phosphorus and magnesium are 3.694 (%) and 0.107 (%) respectively. The highest values of lead, chromium, cadmium, zinc, manganese and iron are 0.241 mg/kg,0.477 mg/kg,0.311 mg/kg,0.414 mg/kg,0.321 mg/kg and 0.212 mg/kg respectively. Equal value of cobalt is 0.051 mg/kg. The lowest values of copper and nickel are 0.043 mg/kg and 0.047 mg/kg respectively with alfalfa plant if compared with the treated wastewater Table (2).

3.3.2 Oat Plant

The results showed that the lowest values of nitrogen, potassium and magnesium are 0.049 (%), 2.41 (%) and 0.304 (%) respectively, while the highest values of phosphorus and calcium are 4.358 (%) and 0.285 (%) respectively. The highest values of copper, lead, chromium, cadmium, cobalt, manganese and nickel are 0.459 mg/kg,0.308 mg/kg,0.310 mg/kg,79.200 mg/kg,0.055 mg/kg,0.735 mg/kg and 0.135 mg/kg respectively. The lowest values of zinc and iron are

0.002 mg/kg and 0.118 mg/kg respectively with oat plant if compared with the treated wastewater Table (2).

3.3.3 Barley Plant

The results showed that the highest values of nitrogen, phosphorus, potassium, magnesium and calcium are 2.137%, 4.414%, 215.10%, 0.326% and 0.002%, respectively. The lowest values of copper, chromium, zinc, manganese and iron are 0.045 mg/kg,0.209 mg/kg,0.228 mg/kg,0.151 mg/kg and 0.000 mg/kg respectively. Equal values of cadmium and nickel are 0.310 mg/kg and 0.050 mg/kg respectively. The highest values of lead and cobalt are 0.238 mg/kg and 0.054 mg/kg respectively with barley plant if compared with the treated wastewater Table (2).

3.4 Comparison between 3 plants in summer agriculture with wet sludge soil

Comparing results represented generally in Figures (8 and 9) show that millet has the highest values of elements from 0.338%, 23.04%, 45.90%, 0.701% and 8.44% for P, Pb, Mn, Ni and Fe followed by cowpea from 0.139%, 33.02%, 3.165% and 3.414% for Mg, Cu, Cd and Co and then Sudan grass from 1.74%, 2.530%, 0.335 and 93.85% for N, K, Ca and Cr respectively. Cowpea and Sudan grass have equal value from 55.32% for Zn by irrigation using fresh water while millet has the highest values of elements from 2.40%, 0.167%, 23.49%, 115.50%, 0.512%, 96.71% and 0.472% for N, Mg, Pb, Cr, Co, Zn and Ni followed by Sudan grass from 4.380%, 43.28%, 29.68% and 94.30% for K, Cu, Mn and Fe and then cowpea from 0.276%, 0.465% and 0.485% for P, Ca and Cd respectively by irrigation using treated waste water with wetted sludge soil.

3.5 Comparison between 3 plants in winter agriculture with wet sludge soil

Comparing results represented generally in Figures (10 and 11) show that oat has the highest values of elements from 0.285%, 0.459%, 0.308%, 79.200%, 0.055%, 0.735% and 0.135% for Ca, Cu, Pb, Cd, Co, Mn and Ni followed by alfalfa from 8.573%, 286.40%, 0.477%, 0.414% and 0.212% for N, K, Cr, Zn and Fe and then barley from 4.414% and 0.326% for P and Mg respectively by irrigation using fresh water, while alfalfa has the highest values of elements from 4.247%, 0.333%, 0.051%, 0.326% and 0.283% for N, Cr, Co, Zn and Mn followed by oat from 4.330%, 0.329%, 0.002% and 0.165% for P, Mg, Ca and Fe and then barley from 194.10% and 0.050% for K and Ni respectively. Oat and barley have equal values from 0.046% and 0.235% for Cu and Pb while alfalfa, oat and barley have equal value from 0.310% for Cd by irrigation using treated waste water with wetted sludge soil.

This was similar results obtained by [27], the three macrophytes were used to promote good dewatering, nutrients removal for sludge treatment wetlands. However, the higher performances were achieved by Zizaniopsis bonariensis, followed by Thypha domingensis and Cyperus papyrus.

3.6 Comparison between different plant in summer and winter agriculture with dry sludge soil

Cowpea and Sudan grass plants are developing slower with dried sludge soil by irrigation using treated waste water while cowpea plant has not developed at all by irrigation using fresh water. Millet plant has developed in the production and formation of fruits and seeds by irrigation using fresh water and treated waste water while Sudan grass plant has developed in the production and formation of fruits and seeds by irrigation using freshwater with dried sludge soil in summer season.

In winter, oat plant has developed in the production and formation of fruits and seeds by irrigation using fresh water and treated waste water while alfalfa plant has developed in the production and formation of fruits and seeds by irrigation using freshwater and treated waste water with dried sludge soil. Barley plant is developing slower with dried sludge soil by irrigation using fresh water while barley plant has developed in the production and formation of fruits and seeds by irrigation using treated waste water. This is in accordance to the results obtained by [28], Four crops were tested in soils fertilized with converted and dried sludge.

Table 2-Macro-nutrients and micro-nutrients (heavy metals) concentrations in plant tissue after cultivating through the summer and winter agriculture

Parameter / Plant	N	P	K	Mg	Ca	Cu	Pb	Cr	Cd	Co	Zn	Mn	Ni	Fe
	%					mg/kg								
	Summer agriculture													
Millet (water)	1.71	0.338	1.622	0.122	0.209	32.95	23.04	55.47	3.102	3.295	47.57	45.90	0.701	8.44
Cowpea (water)	1.62	0.300	0.167	0.139	0.124	33.02	22.99	69.58	3.165	3.414	55.32	32.46	0.673	4.86
Sudan grass (water)	1.74	0.291	2.530	0.079	0.335	30.29	22.92	93.85	0.485	0.506	55.32	40.74	0.372	4.86
Millet (treated)	2.40	0.225	0.107	0.167	0.379	29.69	23.49	115.50	0.470	0.512	96.71	22.86	0.472	8.19
Cowpea (treated)	2.30	0.276	3.385	0.136	0.465	23.27	23.14	62.78	0.485	0.496	43.58	27.33	0.276	25.44
Sudan grass (treated)	1.87	0.249	4.380	0.046	0.313	43.28	23.34	65.06	0.484	0.499	53.97	29.68	0.373	94.30
	winter agriculture													
Alfalfa (water)	8.573	3.694	286.40	0.107	0.003	0.043	0.241	0.477	0.311	0.051	0.414	0.321	0.047	0.212
Oat (water)	0.049	4.358	2.41	0.304	0.285	0.459	0.308	0.310	79.200	0.055	0.002	0.735	0.135	0.118
Barley (water)	2.137	4.414	215.10	0.326	0.002	0.045	0.238	0.209	0.310	0.054	0.228	0.151	0.050	0.000
Alfalfa (treated)	4.247	4.219	181.00	0.274	0.000	0.045	0.232	0.333	0.310	0.051	0.326	0.283	0.049	0.030
Oat (treated)	1.527	4.330	143.90	0.329	0.002	0.046	0.235	0.232	0.310	0.050	0.215	0.223	0.049	0.165
Barley (treated)	2.028	4.255	194.10	0.309	0.001	0.046	0.235	0.226	0.310	0.050	0.300	0.245	0.050	0.017

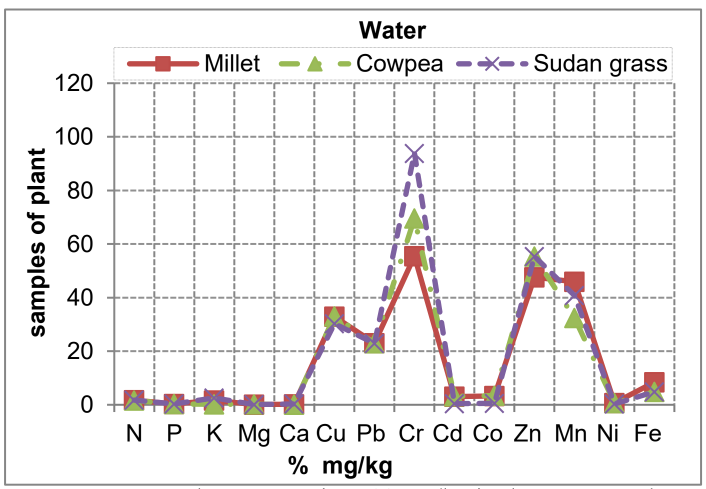

Figure 8- Heavy metal concentrations % mg/kg in the summer plants irrigated by fresh water

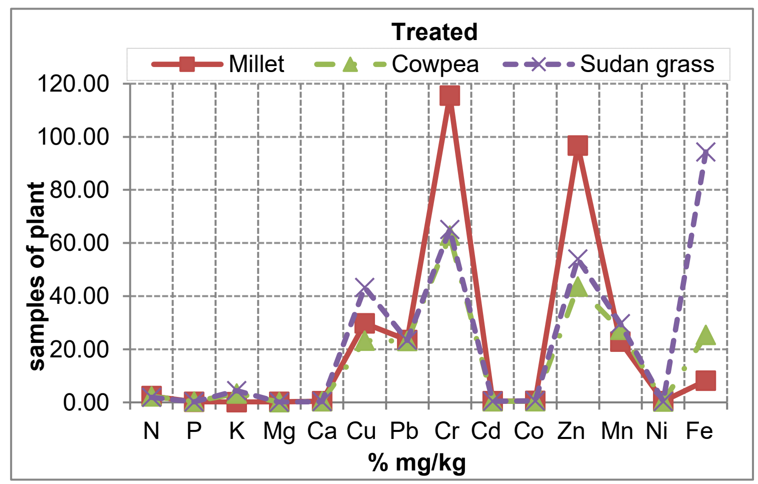

Figure 9- Heavy metal concentrations % mg/kg in the summer plants irrigated by treated wastewater

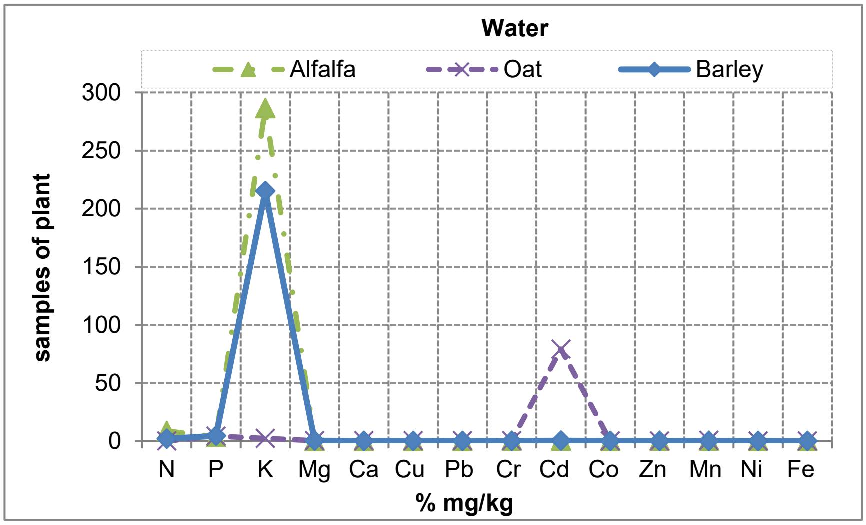

Figure 10- Heavy metal concentrations % mg/kg in the winter plants irrigated by fresh water

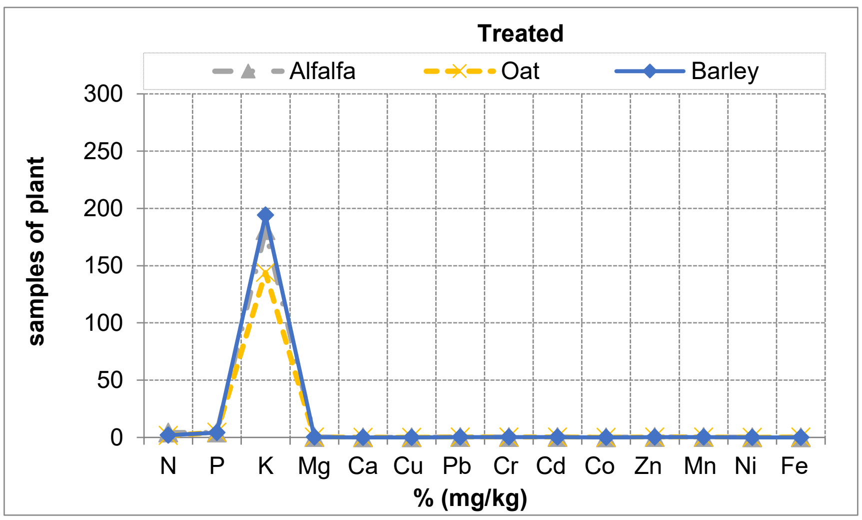

Figure 11- Heavy metal concentrations % mg/kg in the winter plants irrigated by treated wastewater

3.7 green fodder crops

The feed is one of the important elements in animal products, increased demand for animal products leads to increase demand for feed, and noted that the availability of animal feed is less than the needs required for the animal sector, leading to the emergence of the feed gap in Egypt, a lack of animal products could cover by import animal products or import the feed or increase of feed production. The needs of livestock feed in Egypt during the average period 2003-2008. There are about 12 million units of animal in Egypt. The requirements of the livestock feed about 39.8 million tons of green fodder, about 9.6 million tons of straw and about 15.9 million tons of concentrated feed [29].

This study evaluated of six summer fodder crops at Kafr Al-Hamam Agricultural Research Station, Agric. The results showed that pure stand of pearl millet gave higher total fresh and dry forage yields than either Sudan grass or teosinte, whereas cowpea pure stand gave higher total fresh and dry forage yields compared with sole planting of either guar or lima bean [30].

Plants are included in certain proportions in the manufacture of fodders and they are rich in some elements (nutrients - protein - carbohydrates - fats).

It was found that can be used as green fodder without entering into manufacturing, and thus expanding the cultivation of such plants in sewage sludge has a high economic return or payback but must be make bioassay test for analyzing the accumulated heavy metals and other parameters in the growing plants and their effects on the animal productions.

4. Conclusions

This present study characterized the sewage sludge treatment using different types of plants (millet, cowpea, Sudan grass, alfalfa, oat and barley) through summer and winter seasons by irrigation using fresh water and treated wastewater. It is concluded from the results that millet plant is the best types by irrigation using fresh water followed millet plant by irrigation using treated waste water in summer season. In winter, oat plant is the best types by irrigation using fresh water followed alfalfa plant by irrigation using treated waste water. And finally we can use sludge as a fertilizers. The authors found the results need further studies on constructed wetland for municipal sewage sludge treatment by using these plants as green or additive fodders and it has no harmful effect on animal health.

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