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The Egyptian Experience in Sewage Sludge Recycling in Agriculture

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Abstract: Cairo and Alexandria produces (about 400,000 and46,000 tones of sludge dry solids (tds) annually), respectively. The Cairo and Alexandria Sludge Disposal Studies included sludge sampling programme and analysis which has been completed on all Cairo and Alex in order to characterize the quality of raw, digested and composted sludges. The results gave confidence that all sludges were quite acceptable for agricultural use. Extensive field trials programme with wide range of arable field and fruit crops were grown over 6 successive seasons to evaluate the sludge recycling in agriculture. Vegetables and root crops were excluded. The yields of crops fertilized with sludge were consistently equal to and often greater than those obtained by the farmer practice. The results have shown that sludge has improved the nutrient content of the crops, including that of the trace elements, which are often deficient in crops and the human diet in Egypt. Increases in the heavy metal content of plants were negligible due to the calcareous soil conditions of Egypt.

Key words: Egypt · Sewage sludge · Nutrients · Heavy metals · Yields

INTRODUCTION

The implementation of wastewater projects in the major cities of Egypt Cairo and Alexandria will result in large quantities of sewage sludge (raw sludge, digested sludge and composted sludge) being produced and requiring disposal. The Greater Cairo Wastewater Project will eventually result in about 0.4 million tonnes dry solids (tds) per year years or so and Alex 46,000 tds y^{-1} [1, 2]. Disposal routes must be environmentally and socially acceptable and cost-effective. Agriculture may offer the most sustainable and beneficial outlet for sewage sludge, but there are concerns about protecting the environment and human health and its practicality. The principal environmental concerns are due to the inevitable presence of potentially toxic elements (PTEs - mainly heavy metals) and human pathogens [3].

Sewage sludge should be regarded as a natural resource to be conserved and reused, rather than discarded. Its use in agriculture is widely regarded as the newly reclaimed soils in Egypt are characterised by low fertility, high salt content and poor moisture retention [4]. Several investigators indicated the efficiency of different sewage sludge in improving soil characters or increase the productivity of such soils [5-12] Several studies have been undertaken in Egypt but we will focus on Cairo and Alexandria effluent and sludge reuse studies as they are the most significant and comprehensive studies [2, 13].

The Cairo and Alexandria Sludge Disposal Studies has been initiated under the Mediterranean Environmental Technical Assistance Program, funded by the European Investment Bank and promoted by the Cairo and Alexandria Wastewater Organisations, in order to resolve at least part of the difficult problem of sewage sludge disposal in the Cairo and Alexandria areas, which otherwise will become an overwhelming problem once all of the wastewater treatment plants (WWTPs) become operational. The objective is to demonstrate the practical and safe reuse of sewage sludge produced by Cairo and Alexandria and thus serve as a demonstration programme and information source for similar towns and cities in Egypt and warm climates beyond.

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Table 1: Analysis of sludge, farmyard manure and soil samples by Wrc

Sample type	Chicken manure	Farm yard manure	Air dried digested sludge	Sludge compost	Air dried raw sludge	Air dried raw sludge
Source	Bilbeis	km 58	Zenein	Alex.	Helwan	Berka
N (mg g^{-1})	32.6	11.0	14.0	18.3	25.6	23.3
P (mg g^{-1})	8.88	3.01	4.97	6.88	6.93	5.21
K (mg kg^{-1})	16800	23200	1230	3570	1780	1860
Mg (mg kg^{-1})	4150	10900	4950	11000	4470	5080
Ca (mg kg^{-1})	17300	27700	58800	130000	53900	63300
Fe (mg kg^{-1})	595	24200	25900	18900	16400	21500
Cu (mg kg^{-1})	27.9	48.2	407	454	258	435
Cd (mg kg^{-1})	<0.122	0.174	2.3	1.36	1.44	2.4
Cr (mg kg^{-1})	2.3	38.9	156	113	90.6	1330
Ni (mg kg^{-1})	5.87	29.3	48	37.2	42.4	69.4
Pb (mg kg^{-1})	2.45	25.6	383	295	260	344
Zn (mg kg^{-1})	175	143	1780	972	1340	1690
F (mg kg^{-1})	46	58	58	180	69	96
Mo (mg kg^{-1})	<1.0	<1.0	4.0	<1.0	<1.0	10
As (mg kg^{-1})	<2.45	<2.49	3.44	7.34	<2.48	5.6
Se (mg kg^{-1})	<2.45	<2.49	<2.42	<2.48	<2.48	<2.44
Hg (mg kg^{-1})	<1.22	1.53	2.22	1.43	1.36	1.97
VS (%)	87.5	33.6	53.3	32.9	62.6	46.5
DS (%)	90.3	90.6	30.7	92.1	93.2	93.8

MATERIALS AND METHODS

The Cairo study commenced in July 1995 and was completed in March 1999 and Alexandria commenced in October 1998 and was completed by June 2001. A 3 year programme of sludge sampling and analysis has been completed on all Cairo's WWTPs in order to characterise the quality of the sludges. Similar approach was adopted in Alexandria for 20 months sampling programme. The sludges have been analysed for a wide range of determinants, including nutrients, heavy metals and pathogens. A summary of some of the results are given in Table 1, which also includes some data of the composted sludge from Alexandria.

The Cairo Study established 30 field trials, covering about 200 feddans (83 hectares). A wide range of arable crops have been grown over successive winter and summer seasons, including wheat, barley, fodder and grain maize, berseem, soya bean, faba bean, sesame, sorghum and cotton. Vegetables and root crops were excluded. A number of long-term fruit trials were also established and included grapevine, citrus, olive, banana, peach, apple, pear, persimmon and custard apple. The primary objectives of the trials were to evaluate sludge as a replacement for farmyard manure, to show that sludge performed at least as well as traditional methods and that it can be used safely. Farms were selected as trial sites to evaluate the agricultural use of sewage sludge, encompassing the major soil types and crop husbandry practices within the nominal sludge 'marketing' area around Cairo and Alexandria. Six main sites were selected around Cairo and three are being established near Alexandria. A total of 17 demonstration field trials were established with composted sludge from Alexandria involving several crops.

Cairo Wastewater Treatment Plants currently produce air dried raw or digested sludge which is pushed to drying beds and stocked pile for six months prior usage. In Alexandria sludge is composted by windrow turning. The study indicated that the thermophilic composting temperatures of 55 - 65 oCis evolved during composting The temperature of the compost is stable within this range for up to two months and is relatively insensitive to the frequency of turning. Under Egyptian conditions to maintain a relatively high organic matter content in the product for its soil conditioning value, so complete stabilization is not necessary.

RESULTS

Sludge Quality: The sludge quality surveys have shown the relative consistency of sludge quality at each WWTP, compared with the very variable quality of farmyard manure. However, the management and control of the sludge treatment and distribution operations need to be improved to ensure that this management strategy is sustainable, environmentally acceptable, cost-effective and minimises the potential risks to human health [13].

Table 2: Occurrence of pathogens in samples of air-dried sewage sludge as collected from Abu Rawash, Berka, Zenein (digested) and Alexandria (composted) WWTPs (fresh sludge basis)

Pathogen	Abu Rawash	Berka	Zenein	Alexandria
Bacteria (MPN g^{-1})				
Faecal coliforms	5.3 x 105	1.3 x 106	2.2 x 103	nd
Salmonella	50% positive	100% positive	50% positive	25% positive
n	2	3	2	4
Parasites (% samples containing eggs within ranges, eggs g^{-1})				
Eimeria sp.	33% 1-25	50% 1-25	negative	negative
Ascaris	50% 1-25	33% 1-25	negative	25% 1-25(1)
		17% 76-100(1)		
Trichostrongylides	negative	negative	negative	negative
Fasciola sp.	negative	negative	negative	nd
n	2	6	2	4
Note:	(1)	Dead eggs		

Table 3: Typical nutrient inputs according to volume or weight of sludge applied

Sludge type	Application rate	Available nutrients (kg/fd) N	P2O5	K2O
Air-dried undigested sludge	1 m^3/fd	10	16	1.7
	1 t/fd	15	23	2.4
Air-dried digested sludge	1 m^3/fd	12	21	2.5
	1 t/fd	17	30	3.6
Composted sludge	1 m^3/fd	11	18	3.4
	1 t/fd	16	25	4.8

Assuming sludge density of 0.7 t/m^3

Table 4: Nutrient contents of some types of sludge from Cairo and Alexandria compared with farmyard manure

Parameter	units	Undigested sludge Berka	Abu Rawash	Helwan	Digested sludge Zenein	Compost sludge Alexandria	Farmyard manure Local	Chicken manure Local
Organic matter	%	39	53	24	42	25	25	53
Density	t/m^3	0.7	0.7	0.8	0.6	0.6	0.6	0.6
N	%	1.7	1.4	0.9	1.7	1.6	0.8	2.6
P	%	1.1	0.7	1.0	1.3	1.1	0.9	1.3
K	%	0.2	0.2	0.2	0.3	0.4	0.7	0.8
Fe	%	1.4	1.1	1.3	1.2	1.1	1.0	0.2
Mn	mg/kg	221	362	233	307	219	288	196
Zn	mg/kg	688	778	570	697	524	96	174
Cu	mg/kg	279	143	203	179	239	94	125

Microbiological Properties of Air-dried Sludges: Faecal coliform bacteria were present in high numbers in the air-dried raw sludges from Abu Rawash and Berka, but lower in the Zenein dewatered digested sludge (Table 2). Salmonella were present in all types of sludge but not in every sample. Eggs of Trichostrongylides and Fasciola sp. were not found in any of the samples but Eimeria was present only in Abu Rawash and Berka sludges in 33 % and 50 % of samples, respectively within the lowest range of detection (1 - 25 eggs g^{-1}). A lumbricoides was found in all sludge types, except digested, but most samples contained only dead eggs.

Nutrient Content of Sewage Sludge: Sewage sludge contains agronomically valuable amounts of N and P, in addition to other major and minor elements required for plant growth, including Fe, Mn, Zn and Cu, which frequently limit crop yields in Egyptian soils (Table 3 and 4), especially on the reclaimed lands. Typically, solar-dried sludge from Cairo's WWTPs contains 1.7 % and 0.8 % of total N and P, respectively. The total K content is relatively small in comparison and approximately 0.3 %. Organic manures are applied to land on a volumetric basis in Egypt and 1 m^3 of solar-dried sludge typically supplies 11.5 kg N and 6.0 kg P (19 kg N t^{-1} and 10 kg P t^{-1} on a dry solids basis). Similar results were obtained by [9-12].

Table 5: Recommendations for the use of different sludges and farmyard manure for sesame production on newly reclaimed desert soils

Manure type	Regularly treated soil	Previously untreated or infrequently treated soil
Raw sludge	5 m^3 fd^{-1}	20 m^3 fd^{-1}
Digested sludge	5 m^3 fd^{-1}	10 m^3 fd^{-1}
Farmyard manure	10 m^3 fd^{-1}	20 m^3 fd^{-1}

Table 6: Cumulative effects of sludge on the yields of field crops relative to normal farmer practice

Number of consecutive applications of 10 m^3 fd^{-1}	Crop	Increase above normal farmer practice (%)
2	Barley grain	22
3	Forage maize	36
4	Wheat grain	100

Heavy Metals: The detailed investigations on heavy metals in sludge carried out by the studies have shown that the quality of sludge produced in Cairo and Alexandria are similar that of other industrialised countries (Table 1). Also, the heavy metal concentrations are well within the standards required for agricultural use and are not a barrier to reuse and do not limit rates of sludge application on farm land [14].

Effect of Sewage Sludge in Field Crop Production: The field trials programme demonstrated the effectiveness of solar-dried raw, digested, composted sewage sludges and farmyard manure as fertilizers and soil conditioners for arable crop production on alluvial clay soils of the Nile delta and sandy soils on reclaimed land. The main factors influencing crop responses to the applied sludges were rapid and slow N release characteristics of the sludge; improved fertility of soil from cumulative applications of sludge or manures; crop requirement and sensitivity to N; soil type; and irrigation method

The results provided a clear basis for recommending the optimum rates of application of raw and digested sludge types and farmyard manure on clay soil, as follows [14]:

Raw Sludge: 20 m^3 fd^{-1} (30 t fd^{-1}) per crop for all crops, except soyabean which has an optimum of 10 m^3 fd^{-1}.
Digested Sludge: 10 m^3 fd^{-1} (15 t fd^{-1}).
Farmyard Manure: 10 m^3 fd^{-1} (15 t fd^{-1}).

On clay soil, digested sludge gave the largest initial fertilizer response compared with other manures tested. As a general recommendation, the suggested optimum rates of application of raw digested sludge and farmyard manure on reclaimed desert soil are 20 m^3 fd^{-1} 10 m^3 fd^{-1} and 20 m^3 fd^{-1}, respectively. These rates should be reduced where specialist crops are grown with high N sensitivity (e.g. sesame), depending on the fertility of the soil after frequent additions of sludge or farmyard manure (Table 5). These results were confirmed [9-12]. Also [15] came to similar conclusion

Residual Effect of Sewage Sludge: Sewage sludge has important cumulative and residual value for field crop production on reclaimed desert soils. Yields of crops grown on land treated previously with sludge may be increased by 10 - 20 % compared with normal farmer practice [14]. Frequent applications of sludge to reclaimed soil increase soil fertility and can reduce inorganic N fertilizer requirements (Table 6).

Chemical Composition of Crops on Sludge-treated Soil: Extensive chemical analysis of field and fruit crops from the trials (25,000 individual plant tissue analyses were reported by the Study) did not reveal any significant relationships between heavy metal additions from sludge to soil and the concentrations present in plant tissues, which were in the normal ranges reported for crop plants in Egypt. In contrast to the heavy metals, significant and consistent effects of sludge and farmyard manure (FYM) on NPK content of crops were evident. The relative effectiveness of the different organic materials and N fertilizer value, based on observed patterns in crop N content, is as follows:

Digested sludge > FYM > N fertilizer > Raw sludge

Increased N contents in the tissues of crops grown in the season after sludge application, compared with normal farmer practice, show that sludge N also has important residual value. The application of FYM consistently increased the K status of crops relative to the other soil amendments and controls when high quality material was supplied. FYM is a valuable source of this major plant nutrient in Egyptian agriculture [13, 14].

Features derived from of Sludge Reuse Experiences in Egypt:

- A considerable amount of research has been carried out on sludge in Egypt, in addition to extensive international research and operational information.
- The responses of a wide range of field and fruit crops to sludge application are consistent with international experience, with enhanced plant growth and economic yield due to the supply of nutrients and trace elements and benefits to soil conditions from organic matter in the case of sludge. A large number of field trials on sludge reuse have been carried out by various studies, of which the Alexandria Effluent and Sludge Reuse Study and the Cairo Sludge Disposal Study are key examples from which scientifically-based practical guidance and extension have been derived [14, 16].
- Heavy metal accumulation in soil following sludge reuse remains an issue of concern for many in Egypt, but the overwhelming weight of scientific evidence from the local studies, places this in an appropriate perspective. Modelling shows clearly that it will take many decades, or even centuries, of regular sludge application to achieve the precautionary soil limit values adopted in many countries [14].
- For some elements, such as zinc and copper, concentrations in soil often do not meet the minimum levels required for optimum crop growth. This is due to the generally calcareous nature of Egyptian soils, limiting plant uptake. This is responsible for widespread trace element deficiencies which is also reflected in human dietary intake as clinical zinc deficiency in humans has been found in Egypt.
- The pathogen content of sewage in Egypt is large and sludge need to be treated to minimise the potential risks of disease transmission, particularly to farm labourers who are exposed during manual field operations and who will have low appreciation of hygiene precautions. The potential risks have not been well quantified by epidemiological studies, although there is much appropriate international knowledge. The means of achieving hygienic sludge are well understood but the approaches adopted in, say, Europe usually involve high cost. For sludge, low technology approaches, appropriate for Egyptian conditions, have been successfully tested locally, including lime treatment (cement kiln dust), composting and long-term storage.
- Composting, particularly of municipal solid waste, is a rapidly expanding approach to waste management in Egypt. Composting reduces many of the environmental and hygienic problems associated with organic wastes and provides a stable organic fertiliser which is widely sold to farmers. All of the sludge produced by Alexandria is composted to produce a high quality product that is physically attractive and hygienically safe. This material is sold widely for use on green areas and to local farmers [2, 13].
- Anaerobic digestion of sludge in Egypt is currently done only at Gabal El Asfar WWTP, but this is not considered an appropriate technology for Egypt. Although there are operational benefits in terms of reducing the sludge solids for disposal and heat and power may be realised from the use of the methane produced, the capital costs are large and the sludge still requires additional treatment to make it suitable for farm labourers to handle.
- Currently, the sludges from the WWTPs in Cairo and Alexandria (and presumably other WWTPs in Egypt) are sold to farmers. The price varies but on average is about total cost equivalent to about 6 euro/m^3. Haulage contractors play a major role in the current distribution system and they make profitable business. They purchase bulk quantities of sludge and sell it on to farmers and this arrangement is clearly of concern since it is open to abuse through indiscriminate distribution and non-recording of where and how the sludge is used [2, 16].
- Operational experience of effluent and sludge reuse and hopefully control, will increase rapidly in Egypt and the responsible authorities should be sensitive to the lessons learnt as operational reuse expands. Large-scale controlled reuse of sludge has only commenced in Egypt within the last ten years and so long-term monitoring and operational experience is lacking. Much could be learnt, for instance, from the El Saff effluent reuse project (Helwan) and from the current Ministry of Agriculture national forestry projects that would benefit training and project design, implementation and monitoring.
- The dissemination of well-founded extension information is an essential step in 'marketing' sludge, to inform farmers on appropriate application rates and how they may save on fertiliser costs. This approach is also an environmental and health protection measure to avoid excessive nutrient application, which may otherwise have potential implications for drain and groundwater quality, as well as advising farmers on the hygienic precautions [2, 16].

- High quality analysis is also a clear prerequisite for any environmental monitoring and there are a number of laboratories in Egypt with the necessary capabilities, although not necessarily for all of the parameters required by the effluent and sludge reuse regulations. Examination of a large amount of analytical data from many laboratories clearly indicates that the accuracy and precision of analysis is variable. Data are often reported that are clearly not reasonable given knowledge of the normal patterns of distribution and mobility of elements in sludges, soils and plants. For instance, plant analyses frequently indicate high contents of some heavy metals, but the presence of elevated chromium clearly Indicates soil contamination, since this element is not absorbed by plants. Also, high cadmium concentrations in soil are frequently reported but this is most likely due to well know analytical interference problems from the high calcium content of Egyptian soils. Consequently, there is a need for inter-laboratory comparative analysis programmes to ensure consistency in the accuracy of analytical services.

CONCLUSIONS

A comprehensive scientific analysis of the potential value and safety of using Cairo sludge on agricultural land as a fertilizer and soil conditioner provided the assurance that, many climatic, soil, operational, agricultural and economic factors favour agricultural use of sludges under Egyptian conditions and warm climates. Climatic and soil conditions in Egypt strongly favour a reuse option because calcareous and clay soils limit crop uptake of heavy metals and potential toxicity. Also, the reclaimed land and clay soils are deficient in Zn and Cu, as well as other essential elements which are present in sludge and required for plant growth; and the extensive sunshine exposure, high temperatures and dry conditions provide aggressive and unfavourable conditions for the survival of microbial pathogens.

In addition to these beneficial climatic, soil and operational aspects, a further major advantage favouring reuse as a means of sludge management in Egypt and warm climates is the extensive and constant demand of agriculture for bulky organic manures as fertilizers and soil conditioners. Although these justifications favours the use of sewage sludge in the agricultural land, it is recommended to treat the sludges to higher standards to assure higher levels of security and safety.

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REFERENCES

1. CSDS: Cairo Sludge Disposal Study. 1995a. The agricultural use of sewage sludge in warm climates, with special reference to Egypt. Final Report Phase 1, Volume 1. WRc plc, Medmenham, Marlow, UK.
2. Sludge management strategy for Alexandria 1999. Final report, Phase 2. WRc report No. AESD07, July 1999.
3. Smith, S.R., N.R.. Sweet, G.K. Davies and J.E. Hallett, 1992. Sites with long history of sludge disposal: phase II. Final report to the Department of the Environment. WRc Report No. DOE 3023P. WRc plc, Medmenham, Marlow, UK. (c.f. CSDS, 1995).
4 Balba, A., 1995. Management of Problem Soils in Arid Ecosystems. CRC Press Inc, USA.
5. Hall, J.E. and E.G. Coker, 1983. Some effects of sewage sludge on soil physical conditions and plant growth. In: The Influence of Sewage Sludge Application on Physical and Biological Properties of Soils (G. Catroux, P. L' Hermite and E Suess eds.). D. Reidel Publishing Company, Dordrecht, pp: 43-60.
6. El-Laboudi, A.E., S.A. Ibrahim and M.R. Abd-El Moez, 1988. Trial of getting benefit from organic wastes of food industry. Egypt Journal of Soil Science, 28(2): 289-298.
7. Hall, J.E., 1986. The agricultural value of sewage sludge. WRc Report No. ER 1220-M, WRc plc, Medmenham, Marlow, UK.
8. Smith, S.R., 1996. Agricultural Recycling of Sewage Sludge and the Environment. CAB International, Wallingford, UK.
9. E.M. Abd El-Lateef, 2003. The Effects of Sewage Sludge Application on the Yield and Quality of Berseem and Forage Maize in Newly Reclaimed Soil. 2nd International Symposium of Ecological Sanitation. April 7-11 Lubeck, Germany, pp: 651-654.

10. Abd El Lateef, E.M., J.E. Hall, S.R. Smith and T. Gh Behairy, 2005. The Agronomic Value of Sewage Sludge 2-Effect of different Manure Types and Levels Combined with N Fertigation on Maize Yield and Nitrogen Fertilizer Equivalency Ratio. International Symposium on Fertigation Optimizing the utilization of water and nutrients, Beijing, September 20-24, 2005.
11. Abd El Lateef, E.M., J.E. Hall, S.R. Smith, A.A. Farrag and M.M. Selim, 2007. Bio-Solid Recycling In Warm Climates: A Case Study: Cairo and Alexandria Sludge Reuse Studies. International Conference on sustainable Sanitation: Eco-Cities and Villages, 26-29 August 2007, Dong Sheng China.
12. Abd El Lateef, E.M., J.E. Hall and S.R. Smith, 2009. Evaluation of sewage sludge as a source of plant nutrients and its impact on human health in Mediterranean environments. The 15 International Symposium on Environmental Pollution and its Impact on Life in the Mediterranean Region 11-17 October, 2009.
13. CSDS: Cairo Sludge Disposal Study. 1999b. Scientific Justification for Agricultural Use of Sewage Sludge in Egypt. Final Report, Phase 2. WRc report No. CSDR014. May 1999.
14. CSDS: Cairo Sludge Disposal Study. 1999c. Extension Guide for Agricultural Use of Sewage Sludge in Egypt. WRc report No. CSDR015. May 1999.
15. Manal F. Mohamed, Alice T. Thalooth, Tarek A. Elewa and Amal G. Ahmed, 2019. Yield and nutrient status of wheat plants (Triticum aestivum) as affected by sludge, compost and biofertilizers under newly reclaimed soi. Bulletin of the National Research Centre (2019) pp: 31-43.
16. CSDS: Cairo Sludge Disposal Study. 1999d. Strategic Management Plan for Agricultural Use of Sewage Sludge in Cairo. Final Report, Phase 3. WRc report No. CSDR016. May 1999.