Bio-Solid Recycling In Warm Climates: A Case Study: Cairo and Alexandria Sludge Reuse Studies

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The Problem

- The implementation of wastewater projects in the major cities of Egypt Cairo and Alexandria will result in large quantities of bio-solids (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 per year within the next 10 years or so and Alex 46,000 tds y^{-1} (CSDS,1995 and AESR,2000).

- Disposal routes must be environmentally and socially acceptable, and cost-effective. Agriculture may offer the most sustainable and beneficial outlet for bio-solids, 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

The Approach

- ***The Cairo and Alexandria Sludge Disposal Study*** 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 bio-solids disposal in Cairo and Alexandria areas, which otherwise will become an overwhelming problem once all of the wastewater treatment plants (WWTPs) become operational.

- Bio-solids should be regarded as a natural resource to be conserved and reused, rather than discarded. Bio-solids 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 .

- The objective was to demonstrate the practical and safe reuse of bio-solids 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.

Methods

Sludge quality monitoring programme

- All wastewater treatment plants in Cairo produce air dried raw sludge after thickening or dewatering except Zenin and the Gabal El Asfar where digested sludge is produced .

- In Alexandria sludge is composted by windrow turning .The study indicated that the thermophilic composting temperatures of 55 – 65º C is 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. The compost windrows do not require many turnings to maintain efficient processing, which is desirable for moisture retention since high moisture loss is likely to limit microbiological activity.

- After two months, the loss of volatile solids during composting is about 30 %, indicating that the product is reasonably well stabilized. It is probable that low moisture levels limited further degradation during the later stages of the composting process meanwhile, 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.

- A three year intensive sampling programme was devised in order to characterise the chemical and microbial quality of the available sludge sources. This focused on air-drying and composting so that the analyses of a time series of samples could be statistically evaluated and the variability of the constituents determined. The objective was to evaluate its suitability for use in agriculture to provide reassurance that the quality of the sludge remains acceptable for agricultural use.

- Samples of air-dried sludges, as currently used by farmers were also analysed, as well as dewatered digested sludge from the anaerobic digestion pilot plant and the composted sludge of Alexandria. The focus of these investigations was to determine the microbial quality of the sludge under the current management practices, and to recommend how these may be adapted, as necessary, to produce sludge products that are safe for farm labourers, as they are the most exposed individuals to potential disease transmission when spreading sludge by hand.

Field trials programme

- 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. Sludge application was done by hand, either by broadcast for field crops or by pit for fruit trees or mechanically by muckspreader . 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.

- A total of 17 demonstration field trials were established with composted sludge from Alexandria. There were 12 arable trials, some of which were single season trials but most were based on rotations involving several crops. Of these, seven trials were on reclaimed desert sand soil, and four trials on reclaimed calcareous loam soil .

* 1Feddan = 4200m^2

- 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 were established near Alexandria .

- These were mostly on reclaimed desert land since such soils have high demands for organic matter and nutrients. Also the larger farms on the reclaimed land are likely to be much more accessible and attractive operationally for delivering sludge than the small farms of the delta.

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.

Table 1 Chemical properties (mean values and 95% confidence limit) of solar dried sludges from different WWTP and of livestock manures from local sources (Units: density as t m3; ds, VS, N, P, K and Fe as %, other elements as mg kg-1)

WWTP	Density	ds	VS	N	P	K
Abu Rawash	0.74	87.2 ±6.1	51.9 ±14.7	1.61 ±0.49	0.57 ±0.28	0.23 ±0.07
Berka	0.69 ±0.08	90.7 ±5.0	37.2 ±6.8	1.71 ±0.27	0.88 ±0.29	0.24 ±0.08
Helwan	0.82	93.3 ±4.5	27.0 ±5.9	0.85 ±0.13	0.61 ±0.45	0.19 ±0.04
Zenein	0.63 ±0.07	89.1 ±6.6	42.0 ±6.8	1.79 ±0.31	1.06 ±0.35	0.38 ±0.17
Alexandria	nd	88.5 ±10.0	25.2 ±14.8	1.63 ±0.52	1.09 ±0.39	0.38 ±0.18
FYM	0.63 ±0.23	90.9 ±5.3	23.8 ±9.3	0.85 ±0.27	0.69 ±0.28	0.70 ±0.17
Chicken manure	nd	79.2 ±29.5	53.1 ±33.1	2.53 ±1.41	1.35 ±2.07	0.75 ±0.86

WWTP	Fe	Mn	Zn	Cu	Ni	Cd	Pb	Cr	Co
Abu Rawash	1.10 ±0.40	286 ±145	656 ±301	168 ±51	51.3 ±32.3	2.57 ±0.70	102.2 ±62.3	36.6 ±30.6	15.1 ±10.4
Berka	1.32 ±0.23	187 ±46	614 ±202	246 ±92	60.2 ±21.1	3.36 ±1.69	90.9 ±50.5	156.0 ±74.5	21.5 ±26.0
Helwan	1.08 ±0.31	180 ±99	489 ±301	148 ±75	28.6 ±17.3	2.01 ±2.22	38.2 ±20.5	93.6 ±60.3	6.7 ±0.7
Zenein	1.12 ±0.22	259 ±89	618 ±225	174 ±38	46.3 ±25.7	3.11 ±1.29	80.2 ±50.2	69.3 ±44.6	12.9 ±7.2
Alexandria	1.09 ±0.26	219 ±50	524 ±212	239 ±100	39.9 ±25.1	3.73 ±1.68	56.7 ±43.7	53.2 ±40.8	12.8 ±5.6
FYM	1.33 ±0.48	264 ±136	99 ±43	88 ±55	33.3 ±12.7	2.79 ±1.45	21.5 ±12.9	49.5 ±18.1	9.8 ±5.0
Chicken manure	0.24 ±0.19	196 ±92	174 ±293	125 ±215	47.8 ±71.8	1.82 ±0.78	15.8 ±8.2	9.2 ±7.4	4.8 ±1.5

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. *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.

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	5.3×10^5	1.3×10^6	2.2×10^3	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 17% 76-100(1)	negative	25% 1-25(1)
Trichostrongylides	negative	negative	negative	negative
Fasciola sp.	negative	negative	negative	nd
n	2	6	2	4

Note: (1) Dead eggs

Nutrient content of bio-solids

- 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, 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).

Heavy metals

- Heavy metals was a major concern and was seen potentially as a major restriction to the use of sludge on agricultural land, particularly from wastewater treatment plants (WWTPs) serving industrial areas .

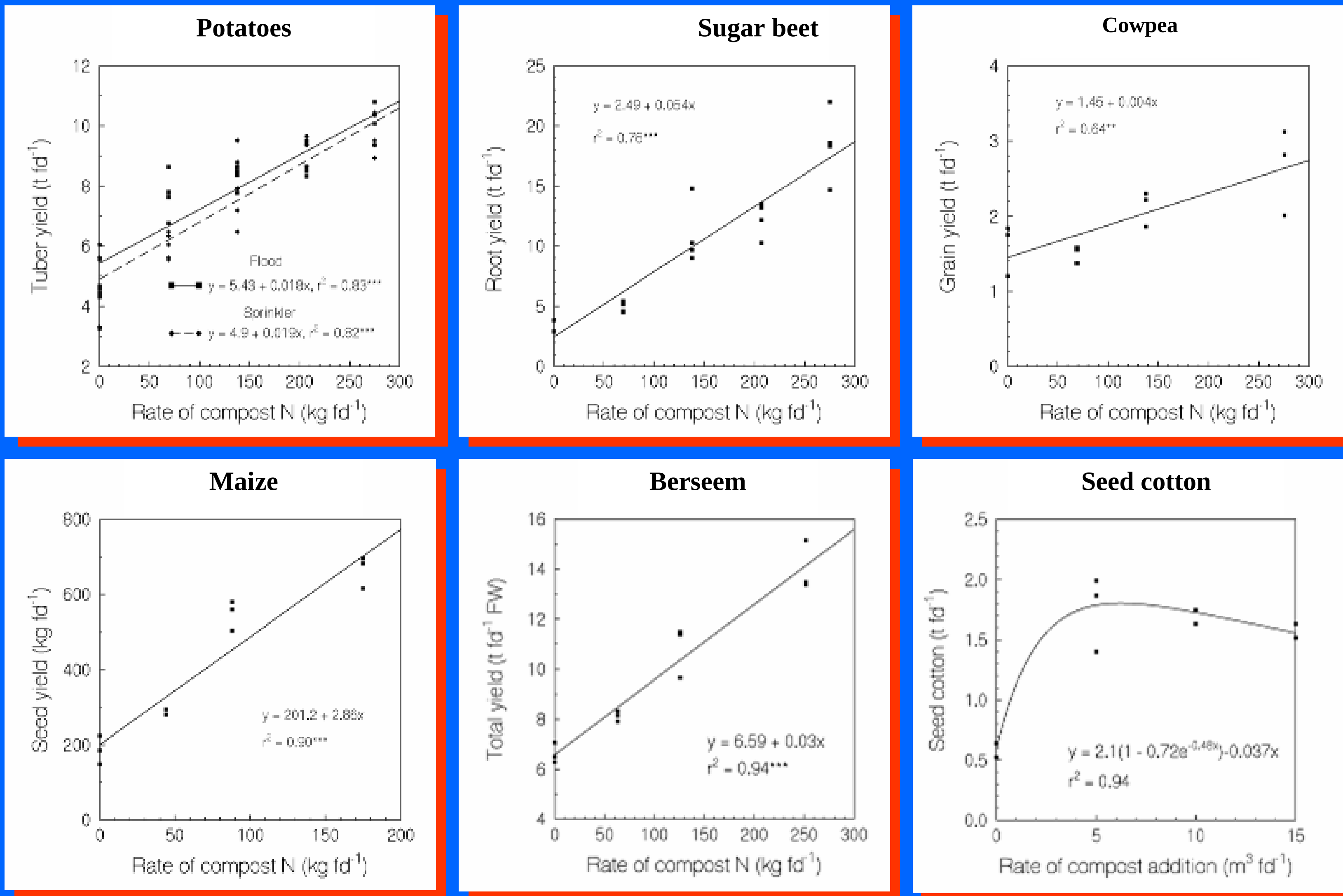
- Detailed investigations on heavy metals in sludge carried out by the Studies have shown that the quality of sludge produced in Cairo is similar that of other industrialised countries and ,the heavy metal concentrations are well within the standards required for agricultural use and are not a barrier to reuse and do not limit rates of sludge application on farmland.

- **Effect of bio-solids on field crop production**

• The field trials programme demonstrated the effectiveness of solar-dried raw , digested and 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 , digested and composted sludge types and farmyard manure on clay soil, as follows:
  - 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 and composted sludge and farmyard manure on reclaimed desert soil are 20 m^3 fd^{-1} , 10 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

Yield Responses to Sludge Compost



Residual effect of bio-solids:

- 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. Frequent applications of sludge to reclaimed soil increase soil fertility and can reduce inorganic N fertilizer requirements.

- All crops may be treated within a rotation provided that due diligence is given to balance K supply with inorganic fertilizers and that the sensitivity to N of certain crops, such as sesame and legumes, is considered. Farmyard manure can be used as an effective source of K and, if inorganic K fertilizers are not available, alternate dressings of sludge and FYM should be applied to balance NPK inputs to soil.

Table 3 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

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 byCairo Study and 17,000 by Alexandria 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:

Composted sludge $\geq$ Digested sludge > FYM $\geq$ N fertilizer $\geq$ 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.

Conclusions

- A comprehensive scientific analysis of the potential value and safety of using Cairo and Alexandria 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 bio-solids in the agricultural land , it is recommended to treat the sludges to higher standards to assure higher levels of security and safety.