Recycling of Treated Sewage Sludge in Sustainable Agriculture

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ABSTRACT

Agricultural utilization of organic wastes amendments has been shown to be a sound alternative for both waste recycling and soil fertility improvement. Also, attention had been paid to use the biological agents that most cheap and safe for agricultural application in poor sandy soils. In this respect, irradiated sewage sludge and individual and dual inoculants of Azospirillum, Rhizobium and Arbuscular mycorrhizae fungi were applied for reclamation and development of low fertile sandy soil. The fertilizer value of sewage sludge has been known for a long time, but the concomitant problems of heavy metals in soil, as a result of its continuous applications, have only been recognized recently. Most of the studies were devoted to follow up the effect of high concentrations of metals when sewage sludge was applied, but no attention has been accelerated about its effect on soil microorganisms. Adverse effects of sewage sludge on microbial activity and populations of cyanobacteria, Rhizobium, Mycorrhizae and total microbial biomass have been detected in some cases of Europe. For example, N\textsubscript{2} fixation by free-living heterotrophic bacteria was found to be inhibited at concentrations (mg kg\textsuperscript{-1}) of 127 Zn, 37 Cu, 21 Ni, 3.4 Cd, 52 Cr, and 71 Pb. Impact of biofertilizers combined with irradiated sewage sludge on micronutrients, e.g. Fe, Zn, Mn, Pb availability to clover and wheat plants, and productivity of both crops was the main objective of this study. In this connection, nuclear technology may offer a safety method against pathogenic effects of sewage sludge applied into agricultural ecosystems. Therefore, irradiated sludge is considered as safely source of organic wastes as well as the benefits on enrichment the low fertile soil with available nutrients, which act as a limiting factor for crop production. The N, P and K nutrients uptake by either shoots or grains of tested crops were positively and significantly affected by application of sewage sludge as well as biofertilizers inoculation

Key words: Irradiation/ Recycling/ Sewage/ Treated sludge/ wastes

INTRODUCTION

As a consequence of industrialization during the last centuries, the heavy metal concentration of soils has increased worldwide\textsuperscript{(1)}. Hot spots of soil contamination are located in areas of large industrial activities, where surrounding agricultural areas are affected by atmospheric deposition of heavy metals. Also, agricultural practice, e.g. application of sewage sludge or phosphate fertilizers, has lead to increased metal concentration in soils.

Notwithstanding the intensive use of chemical fertilizers, the efficiency is still lower than expected, especially for N as a nutrient source that is considered a limiting factor for wheat production under low fertile soils. Therefore, attention had been paid to use alternatives such as organic and / or biological agents that most cheap and safe for agricultural application in poor sandy soils. In this respect, irradiated sewage sludge \textsuperscript{(2)}, and individual inoculants of Azospirillum, Rhizobium and Arbuscular mycorrhizae fungi were applied for reclamation and development of low fertile sandy soil \textsuperscript{(3)}. The fertilizer value of sewage sludge has been known for a long time, but the concomitant problems of heavy metals in soil, as a result of its continuous applications, have only been recognized recently. Most of the studies were devoted to follow up the effect of high concentrations of metals
when sewage sludge was applied, but no attention has been accelerated about its effect on soil microorganisms. Asker et al. (4) recognized that the application of sewage sludge had increased the productivity of cotton and alfalfa grown in sandy and calcareous soils. Thus, the application of sewage sludge was related to the rate of addition, physico-chemical properties of sewage sludge and soil-plant relationship. In this respect, Ferreria and Castro (5), found that inoculated alfalfa was positively affected by addition of sewage sludge at rate of 5-10 t ha\(^{-1}\). With regard to the effect of gamma radiation on sewage sludge, Pandya et al. (6) indicated the inhibition of toxic substances that founded in unirradiated sewage sludge. In addition, chickpea plants treated with irradiated sewage sludge had a high quantity of protein than that treated with unirradiated sewage sludge. The bacterial or fungal inoculants have a positive role in increasing the plant productivity (3). Adverse effects of sewage sludge on microbial activity and populations of cyanobacteria, Rhizobium, Mycorrhizae and total microbial biomass have been detected in some cases of Europe. For example, \(\text{N}_2\) fixation by free-living heterotrophic bacteria was found to be inhibited at concentrations (mg kg\(^{-1}\)) of 127 Zn, 37 Cu, 21 Ni, 3.4 Cd, 52 Cr, and 71 Pb (7).

**Agricultural Use of Sewage Sludge**

Sewage sludge is the organic material produced from domestic and industrial waste water and direct run-off from roads. The primary treatment is settlement for about 24 hours, to remove coarse particles. The supernatant liquid receives a secondary treatment by being sprinkled once and sometimes twice through biologically active filters. Further filtration or flocculation (tertiary treatment) may follow before the liquid is discharged into rivers. Sludge which is to be applied to the land is usually digested anaerobically to reduce its water content and smell, and further dewatered mechanically or by allowing it to dry. The composition of sewage sludge is very variable. It depends on the local industrial processes and on the amount of sand and silt that it contains. It is useful as a source of nitrogen and phosphate for plants, but has only a small content of potassium because most remains in the liquid that is discharged into rivers. The organic matter in sewage sludge helps to improve soil structure. When applied to land it therefore has beneficial effects. Problems arise if large amounts are applied too frequently or over a prolonged period and the sludge contains high concentrations of metals which are toxic to plants or animals. Those considered to present the greatest hazard are shown in Table 1. Concentrations vary greatly according to the source of the waste, and particularly on the amount of industrialization and nature of the industrial processes in the catchment area. As examples, chromium and nickel are released by the iron and steel industry, cadmium and lead from the manufacture of batteries, and zinc from zinc plating factories. Zinc and copper predominate in domestic sewage but are usually present in lower concentrations than in sewage that contains waste from industrial processes (8).

Most wastewater treatment processes produce a sludge which has to be disposed of. Conventional secondary sewage treatment plants typically generate a primary sludge in the primary sedimentation stage of treatment and a secondary, biological, sludge in final sedimentation after the biological process. The characteristics of the secondary sludge vary with the type of biological process and, often, it is mixed with primary sludge before treatment and disposal.
Table 1. Concentrations of heavy metals (mg kg$^{-1}$ dry matter) in 42 sewage sludges from England and Wales

<table>
<thead>
<tr>
<th>Metal</th>
<th>Median</th>
<th>Range</th>
<th>kg in 25 t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>—</td>
<td>&lt;60–1500</td>
<td>—</td>
</tr>
<tr>
<td>Cr</td>
<td>250</td>
<td>40–8800</td>
<td>6.3</td>
</tr>
<tr>
<td>Cu</td>
<td>800</td>
<td>200–8000</td>
<td>20.0</td>
</tr>
<tr>
<td>Ni</td>
<td>80</td>
<td>20–5300</td>
<td>2.0</td>
</tr>
<tr>
<td>Pb</td>
<td>700</td>
<td>120–3000</td>
<td>17.5</td>
</tr>
<tr>
<td>Zn</td>
<td>3000</td>
<td>700–49000</td>
<td>75.0</td>
</tr>
</tbody>
</table>


**SLUDGE TREATMENT**

Except when it is to be injected or otherwise worked into the soil, sewage sludge should be subjected to biological, chemical or thermal treatment, long-term storage or other appropriate process designed to reduce its fermentability and health hazards resulting from its use before being applied in agriculture. Table 2 lists sludge treatment and handling processes which have been used in the UK to achieve these objectives.

**SLUDGE APPLICATION**

The concentrations of potentially toxic elements in arable soils must not exceed certain prudent limits within the normal depth of cultivation as a result of sludge application. No sludge should be applied at any site where the soil concentration of any of the parameters mentioned in Section, with the exception of molybdenum, exceed these limits. Maximum permissible concentrations of the potentially toxic elements in soil after application of sewage sludge. For zinc, copper and nickel, the maximum permissible concentrations vary with the pH of the soil because it is known that crop damage from phytotoxic elements is more likely to occur on acid soils.

When sludge is applied to the surface of grassland, the concentrations of potentially toxic elements should be determined in soil samples taken to a depth of 7.5 cm. In order to minimize ingestion of lead, cadmium and fluoride by livestock, the addition of these elements through sludge application to the surface should not exceed 3 times the 10 year average annual rates.

Effective use of organic wastes for agricultural production requires that risks and benefits be documented$^9$. They used two types of sewage sludge, household compost and solid pig manure under field and greenhouse conditions to describe their fertilizer value and effects on soil properties and soil biota, the fate of selected organic contaminants, and their potential for plant uptake. A 3-year field trial on two soil types showed no adverse effects of waste amendment on crop growth, and a significant fertilizer value of one sludge type. Accumulation of N and P was indicated, as well as some stimulation of biological activity and micro-arthropod populations, but these effects differed between soil types. There was no detectable accumulation of polycyclic aromatic hydrocarbons (PAH), di(2-ethylhexyl)phthalate (DEHP), nonylphenol and ethoxylates (NP+NPE) or linear alkylbenzene sulfonates (LAS) after three repeated waste applications, and no plant uptake was suggested by analysis of the third crop (Fig. 1).

A plot experiment with banded sludge was conducted to examine sludge turnover and toxicity in detail. Less than 5% of NP or LAS applied in organic wastes was recovered after 6 months, and less than 6% of DEHP applied was recovered after 12 months.
Potential ammonium oxidation (PAO) at 0–1 cm distance from the banded sludge was stimulated despite toxic concentrations in the sludge, which suggested that contaminants were degraded inside sludge particles. Phospholipid fatty acid (PLFA) profiles suggested a gradual shift in the composition of the microbial community within sludge, partly due to a depletion of degradable substrates.

A pot experiment with sludge-amended soil and soil spiked with contaminants showed no plant uptake of NP, DEHP or LAS. Degradation of LAS and NP added in sludge was delayed and the degradation of DEHP was faster than when the contaminants were added directly to the soil (Fig. 2). In conclusion, adverse effects of organic waste application on soil or crop were not found.

Table 2. Examples of Effective Sludge Treatment Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge Pasteurization</td>
<td>Minimum of 30 minutes at 70°C or minimum of 4 hours at 55°C (or appropriate intermediate conditions), followed in all cases by primary mesophilic anaerobic digestion</td>
</tr>
<tr>
<td>Mesophilic Anaerobic Digestion</td>
<td>Mean retention period of at least 12 days primary digestion in temperature range 35°C +/− 3°C or of at least 20 days primary digestion in temperature range 25°C +/− 3°C followed in each case by a secondary stage which provides a mean retention period of at least 14 days</td>
</tr>
<tr>
<td>Thermophilic Aerobic Digestion</td>
<td>Mean retention period of at least 7 days digestion. All sludge to be subject to a minimum of 55°C for a period of at least 4 hours</td>
</tr>
<tr>
<td>Composting (Windrows or Aerated Piles)</td>
<td>The compost must be maintained at 40°C for at least 5 days and for 4 hours during this period at a minimum of 55°C within the body of the pile followed by a period of maturation adequate to ensure that the compost reaction is substantially complete</td>
</tr>
<tr>
<td>Lime Stabilization of Liquid Sludge</td>
<td>Addition of lime to raise pH to greater than 12.0 and sufficient to ensure that the pH is not less than 12 for a minimum period of 2 hours. The sludge can then be used directly</td>
</tr>
<tr>
<td>Liquid Storage</td>
<td>Storage of untreated liquid sludge for a minimum period of 3 months</td>
</tr>
<tr>
<td>Dewatering and Storage</td>
<td>Conditioning of untreated sludge with lime or other coagulants followed by dewatering and storage of the cake for a minimum period of 3 months if sludge has been subject to primary mesophilic anaerobic digestion, storage to be for a minimum period of 14 days</td>
</tr>
</tbody>
</table>
Fig. 1. The disappearance of DEHP, NP and LAS was monitored in bands of SS high during a period of up to 1 year. Vertical bars indicate standard deviations.

Legume and Non-Legume-Microbe Association as Affected by Irradiated Sewage Sludge Additives on Sand soil.

Koth (2) conducted series of pot experiments to trace the effect of sewage sludge either applied alone or in combination with bio-agents. Sewage sludge was exposed to 12 KGY of gamma radiation to eliminate the pathogens. Amended soils were slugged by 1% w/w. Seeds of clover and wheat crops were inoculated with Azospirillum brasilense, Rhizobium leguminosarum and Arbuscular mycorrhizae fungi (AMF), and their combinations for developing the fertility status of virgin sandy soil. Both crops, clover (Trifolium alexandrinum cv. Sakha 4) and wheat (Triticum aestivum cv. Sakha 69) were planted in soil amended with and without irradiated sewage sludge. The harvests were prepared for analysis. Different growth parameters and microelements (Fe, Zn, Mn and Pb) contents were determined for both crops. He found that with clover and wheat, the enhancement of growth and productivity were maximum in response to soil amendment with sludge and dual inoculation treatments. In this respect, irradiated sludge induced better results than those recorded with the unamended soil. Regarding the inoculants, data showed that dual inoculation of clover with Rh+AM was the best followed by Rh+Sp and AM+Sp. Another view was noticed with wheat where using the dual inoculants of Sp+AM followed by Rh+Sp and Rh+AM resulted in the most promising effects. In all cases, the promoting effect of these inoculants was markedly substantiated in the presence of sewage sludge. He recommended the use of the above-mentioned treatments in order to increase fertility of soils that have such given conditions of experimental low fertile sandy soil, after further application in field trials.

Generally, the micronutrients were significantly concentrated in the shoot and grain as affected by inoculation and sewage sludge (Table 3). Iron (Fe) uptake by shoot was significantly higher than in the grain. In the same direction, sewage sludge enhanced the Fe acquisition by both organs as compared to unamended soil. Dual inoculants are still the best treatments. Combination of Rhizobium and Azospirillum and sewage sludge was the best when shoot-Fe was concerned, while the combined treatment of mycorrhizae plus Rhizobium gives the high value of Fe uptake by grain. Similar trends were observed with zinc, manganese and lead. Also, these metals were concentrated in the shoot than
in the grains. It seems that both wheat organs tended to accumulate more Fe followed by lead, zinc and manganese. For all metals, a significant interaction between inoculation and sewage sludge was calculated.

![Graph](image)

**Fig. 2.** Recovery after 30 days of LAS, NP and DEHP added to Lundgaard soil in SS high or as an aqueous solution (‘Spike’). The pots were seeded with rape at the start of the pot experiment. Vertical bars indicate standard deviations.

Sludge amendment significantly interacted with applied microorganisms and increases the input and availability of micronutrients to plants without harmful effects or toxic symptoms. It means that sludge additives has no severe negative effects on soil or introduced microorganisms as well as on plant growth in general (Table 3). Johansson et al. (10) stated that repeated application of sludge over 12 years at moderate rate of 3 t ha$^{-1}$ year$^{-1}$ on soil cultivated with different legume and non-legume crops, affected several of the biological and chemical parameters but no negative effects on soil microorganisms were detected. Also, the biochemical characteristics of soil may be affected by sludge, as found by Saviozzi et al. (11) who revealed that 5 t ha$^{-1}$ year$^{-1}$ for 12 years reflected a dramtical effects on organic carbon, microbial biomass, urease activity and heavy metal content. They also suggested that even higher levels of sludge should be applied to low fertile soil to restore the fertility lost due to cultivation.
Table 3: Effect of inoculation and irradiated sewage sludge additives on micronutrients uptake by shoot and grain of wheat plants

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Micronutrients uptake mg pot⁻¹</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe S S</td>
<td>Zn S S</td>
<td>Mn S S</td>
<td>Pb S S</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoot</td>
<td>Cont.</td>
<td>AMF</td>
<td>Rh</td>
<td>Sp</td>
<td>AMF+Rh</td>
<td>AMF+Sp</td>
<td>Rh+Sp</td>
</tr>
<tr>
<td>Uninoculated</td>
<td>34.9 g</td>
<td>39.3 cf</td>
<td>46.2 de</td>
<td>38.5 ef</td>
<td>49.0 de</td>
<td>72.0 bc</td>
<td>69.7 bc</td>
</tr>
<tr>
<td>AMF</td>
<td>37.6 fg</td>
<td>57.3 cd</td>
<td>49.6 de</td>
<td>71.0 bc</td>
<td>61.5 cd</td>
<td>61.4 cd</td>
<td>84.6 a</td>
</tr>
<tr>
<td>Rh</td>
<td>3.2 gh</td>
<td>4.5 bc</td>
<td>3.3 fg</td>
<td>2.9 h</td>
<td>4.5 bc</td>
<td>4.5 bc</td>
<td>4.6 bc</td>
</tr>
<tr>
<td>Sp</td>
<td>3.7 ef</td>
<td>4.0 cd</td>
<td>4.8 bc</td>
<td>5.9 ab</td>
<td>5.5 bc</td>
<td>6.9 a</td>
<td>5.4 bc</td>
</tr>
<tr>
<td>AMF+Rh</td>
<td>1.8 e</td>
<td>2.0 cd</td>
<td>2.3 cd</td>
<td>1.9 de</td>
<td>2.2 cd</td>
<td>2.5 cd</td>
<td>3.3 ab</td>
</tr>
<tr>
<td>AMF+Sp</td>
<td>2.1 cd</td>
<td>2.2 cd</td>
<td>2.3 cd</td>
<td>2.1 cd</td>
<td>2.3 cd</td>
<td>2.5 cd</td>
<td>3.3 ab</td>
</tr>
<tr>
<td>Rh+Sp</td>
<td>6.5 f</td>
<td>7.2 cd</td>
<td>7.6 abc</td>
<td>6.8 cd</td>
<td>8.1 ab</td>
<td>8.3 ab</td>
<td>8.6 a</td>
</tr>
<tr>
<td>AMF+Rh+Sp</td>
<td>7.2 bc</td>
<td>7.4 ab</td>
<td>7.5 ab</td>
<td>7.9 ab</td>
<td>8.1 ab</td>
<td>7.7 ab</td>
<td>8.3 ab</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same letter are not significantly different at P ≤ 0.05.

Foliar concentrations of Fe (Table 4) gave an evident that sludge application significantly increased Fe uptake by clover shoot. Similar trend was observed with manganese, zinc and lead. Inoculation also enhanced the uptake of these microelements as compared with the uninoculated control. It is worthy to mention that Rhizobium inoculants had increased the concentration of these elements in clover shoot either applied individually or in combination with mycorrhizae or Azospirillum in soil amended with irradiated sewage sludge.
Table 4
Micronutrient concentration in clover shoot as affected by inoculation and irradiated sewage sludge application.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fe</th>
<th>Zn</th>
<th>Mn</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>control S sludge</td>
<td>Control S sludge</td>
<td>Control S sludge</td>
<td>Control S sludge</td>
</tr>
<tr>
<td>Uninoculated</td>
<td>2.3 i</td>
<td>7.9 j</td>
<td>1.4 j</td>
<td>4.4 gh</td>
</tr>
<tr>
<td>AMF</td>
<td>7.4 i</td>
<td>13.4 ef</td>
<td>2.5 hij</td>
<td>8.7 cd</td>
</tr>
<tr>
<td>Rh</td>
<td>9.0 hi</td>
<td>20.0 ab</td>
<td>3.3 hij</td>
<td>15.3 a</td>
</tr>
<tr>
<td>Sp</td>
<td>8.7 ki</td>
<td>8.8 hi</td>
<td>1.3 j</td>
<td>6.2 efg</td>
</tr>
<tr>
<td>AMF+Rh</td>
<td>10.4 gh</td>
<td>16.9 cd</td>
<td>3.6 hi</td>
<td>10.7 bc</td>
</tr>
<tr>
<td>AMF+Sp</td>
<td>4.2 ki</td>
<td>12.3 fg</td>
<td>1.6 ij</td>
<td>7.1 def</td>
</tr>
<tr>
<td>Rh+Sp</td>
<td>10.4 gh</td>
<td>19.0 abc</td>
<td>2.5 hij</td>
<td>8.8 cd</td>
</tr>
<tr>
<td>AMF+Rh+Sp</td>
<td>5.2 jk</td>
<td>12.8 ef</td>
<td>1.5 ij</td>
<td>7.6 def</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$.

Nodule numbers and dry weight values of clover plants were positively affected by sewage sludge additives and inoculation treatments (Fig 3 a & b). Regarding the inoculation treatments, the data showed a high significant increase in nodule number. Similar trend was observed with sewage sludge addition where the number of nodules recorded highly significant increases as compared with the non-sludged soil. In this respect, the treatment of dual inoculation with Rh+Sp was the best followed by single inocula of Rh. Similarly, dry weight of nodules (Fig 1b) indicates a positive effect of both inoculation and irradiated sewage sludge comparable to uninoculated and unamended controls. Generally, the highest value of nodule dry weight was induced by Rhizobium inoculation solely or in combination with irradiated sewage sludge.
Sewage Sludge Management in Egypt

Since a long period, Egypt has been concentrating its efforts on sanitation services mainly on wastewater treatment, while little priority has been given to sludge management in practice. The primary focus of investment has been addressed to water supply, sewerage networks and wastewater treatment. Until 2004, the percentage of population served by wastewater facilities was very low. More than 80% of the rural areas and about 40% of the urban areas are showing deficits in adequate sanitation facilities (CAPMAS 2004). Currently, a quite small attention is given to sludge management, which is reflected in the local legislations that often simply depend on regulations of industrialized or more advanced countries without any attempt to adapt it to local situations (12).

Egypt is an arid country, the desert represents more than 95% of the total area and only 4% are occupied by overpopulation in a limited strip of the Nile valley and Delta. Due to the rapid increase in population, the cultivated land declined per capita from about 0.23 acre (acre = 4046.9 m<sup>2</sup>) in 1960 to about 0.13 acre in 1996 and will be decreased to 0.09 acre by 2017 (13). The sharp decline of the per capita cultivated land will also reduce the per capita crop production, which will directly affect food security for populations. An important issue in the future is to redistribute the population over a larger area. Therefore, the quest to bring new land under cultivation has been a cornerstone of Egyptian agricultural policy since the 1950s. Over the last 30 years, the Government of Egypt has undertaken a large programme of horizontal expansion of agricultural used land through the reclamation of desert areas. More than 3.29 million acres have been reclaimed and that will be increased in the future (14).

The soil in these reclaimed land are often saline, mild to moderately alkaline (pH 7.7-8.2), contain calcium carbonate in the range from 1-20% and appreciable concentrations of gypsum (hydrated calcium sulphate) (15). Micronutrient element deficiencies are common, particularly manganese, iron and zinc due to the high pH (16). Such soils derived under hot arid conditions are unlikely to cultivate and contain very little organic matter. Furthermore, the coarse nature of these soils, dominated by gravel and sand effects a low fertility and a low water holding capacity. There are considerable requirements for most plant nutrients as well as additional organic matters to improve water holding capacity, soil structure and aeration. Some field pilot studies involved the establishment of a practical system for the safe use of sewage sludge in agriculture in Egypt had been done principally through a series of demonstration field trials and sludge quality sampling programmes. The results of these studies indicated that, the nutrients, trace elements and organic matter present in the sewage sludge
have the potential to increase the yield and quality of crop and to improve the soil conditions for crop growth under Egyptian conditions. The crop response to sludge was equal to and often greater than that from an equivalent quantity of farmyard manure or inorganic fertilizers \(^{(17)}\).

The climatic and soil conditions in Egypt strongly favour the use of sewage sludge for land application. This may be attributed to the following factors \(^{(15)}\):

1. Calcareous and clay soils limit crop uptake of heavy metals and potential toxicity
2. Reclaimed land is deficient in Zn and Cu as well as other essential elements, which are required for plant growth and are present in sludge
3. The extensive sunshine exposure, high temperature, and dry conditions provide aggressive and unfavorable conditions for the survival of microbial pathogens.

However, the quality of produced sewage sludge and conditions of sludge application in Egypt should be more controlled to ensure that the potential hazards to health and the environmental are avoided.

Production of solid sewage sludge in Egypt has followed many scenarios, one of them is the stabilization process by using anaerobic digestion applied in Al Gabel Asfer WWTP, which is the biggest wastewater treatment plant in Egypt. The current sewage treatment capacity is 1800x10³ m³/day and will be increased to 3000x10³ m³/day in 2020. The application of the anaerobic digestion technology for sludge stabilization and power generation in Al Gabel Asfer WWTP has achieved good results and many experiences in operation and maintenance have been gained. Thus, there is an interest in using such technology on large scale in Egypt, especially in big wastewater treatment plants in major cities. Fig. 4 shows the flow diagram of sewage sludge treatment and disposal scenario using the anaerobic digestion processes in Al Gabel Asfer WWTP \(^{(12)}\) (Ghazy et al., 2009).

![Flow diagram of sewage sludge treatment and disposal scenario using anaerobic digestion technology](image)

**Fig. 4.** Flow diagram of the sludge treatment scenario by using anaerobic digestion technology

The agricultural research was carried out in Nawag and El Minia during June and July with the sludge product converted by grass as well as with air-dried sludge for comparison. The experiments were focused on the quality of the substrates as fertilisers in heavy soil from the Nile Delta in Nawag as well as pure sand in both locations. Already the pre-investigation experiments in buckets have shown that the efficiency of even the only partly converted product, as fertilizer is considerably higher than the efficiency of the dry sludge (Fig. 5). In the same time crops developed faster and more biomass in the soil mixed with converted sludge than in soil where the dried product was applied \(^{(17)}\).
The results of the field tests have lead to similar conclusions. Of the 4 tested crops Maize (Durra), Millet (Durra Sucari), Ladyfinger (Okra, Bamia) and Garghir only Maize is developing similar in soils fertilised with converted and dried sludge although negative effects produced by high concentrations of air dried sludge can be also noticed. All other tested plants are developing slower in soil fertilized with dried sludge. In the plots with high concentrations of dried sludge, Ladyfinger, Sorghum and Garghir nearly have not developed at all (Figs. 6&7).

Especially in the sand the converted product demonstrates its quality as soil conditioner because the plants have developed the same height and thickness as in the heavier soil from the Delta, in case of Okra even more. This shows that the converted product has a large ability to adopt and to store water (Figs. 8&9).
CONCLUSIONS

Recycling of sewage sludge in sustainable agriculture systems led many investigators to establish some recommendation and conclusions as following:

**Economic and Social Impact of Using Irradiated Sewage Sludge in agriculture:**
A- Environmental preservation
B- provide alternative source for irrigation and fertilization
C- Minimizing the dependence on chemical fertilizers
D- reduce water consumption
E- reduce the production cost
F- increase the national income (increase the cultivated area and yield)
G- production of highly priced organic commodities for national and international markets

Also, she recommended that:
1) Radiation technology is recommended for sewage sludge disinfection, a dose of 6 KGY is for sewage sludge and a dose of 1 KGY for sewage water
2) Radiation disinfection can replace chlorine which form carcinogenic compounds
3) The use of irradiated sewage sludge is environmentally safe for recycling in agriculture and it preserve human health
4) Irradiated sewage sludge at a rate of (80t/ha) proved to be a good organic fertilizer for sandy and calcareous soils
5) Irradiated sewage sludge is considered a good substitute for peat moss and chemical fertilizer
6) Irradiated sewage sludge resemble a slow release fertilizer capable for sustaining crop production without harming the environment

On the other hand, the sewage sludge and sewage effluent should be carefully used in sustainable agriculture systems. In this respect, sewage wastewater and sludge are considered the main source for environmental pollution. Treatment should be applied in order to eliminate the different contaminants in the sludge before land application. Ionizing radiation is a fast and reliable tool for pollution control. Isotope aided study could be used to quantify the availability of nutrients to plant from sludge, as a consequence the proper application rate could be achieved in order to preserve the environment.

REFERENCES