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UTILIZATION OF SEWAGE AND SLUDGE AS ORGANIC FERTILIZER IN SUSTAINABLE AGRICULTURE

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Abstract

This paper deals with Sludge contains recyclable and agronomical valuable macro and micronutrients. Sludge application on cropland reduces need of synthetic fertilizers; causing sustainability of agriculture Dewatered sludge can be buried underground in a sanitary landfill. It also may be spread on agricultural land in order to make use of its value as a soil conditioner and fertilizer. Since sludge may contain toxic industrial chemicals, it is not spread on land where crops are grown for human consumption. The number of pathogenic and parasitic organisms in sludge can be significantly reduced before application to land by appropriate sludge treatment and potential health hazard is further reduced by the effect of climate, soil microorganism and time after the sludge is applied to the soil.

Key words: organic wastes, sewage sludge, calcareous soil, wheat.

1. Introduction

Sewage sludge consists of by-products of wastewater treatment. It is a mixture of water, inorganic and organic materials removed from wastewater coming from various sources (domestic sewage, industries), storm water run- off from roads and other paved area, through physical, biological, and/or chemical treatments. Sewage sludge is also referred to as biosolids. Various agencies have put forth different definitions of Biosolids. Biosolids are nutrients rich organic materials resulting from the treatment of domestic sewage in a treatment facility. Some regards biosolids as stabilized organic solids derived from biological waste water treatment process, which can be managed safely to utilize their nutrients on sustainable basis, and used for soil conditioning, energy, or other value. The utilization of biosolids/sewage sludge in agriculture is gaining popularity as a source of waste disposal. Biosolids/sewage sludge generally contains useful compounds of potential environmental value. They also contain useful concentration of organic matter, nitrogen, phosphorus and potassium and to lesser extent, calcium, sulphur and magnesium. The availability of phosphorus content in the year of application to agricultural lands is above 50% and is independent of prior sludge treatment. Nitrogen availability is more dependent on sludge treatment. Untreated liquid sludge and dewatered treated sludge release nitrogen slowly with benefits to crop being realized over a relatively long period. An aerobically digested sludge has high contents of ammonia, which is readily available to plants. Thus it is a nutrient enriched fertilizer. The organic matter content in sludge can improve soil physical, chemical, and biological properties with ensuring better cultivation and aquiferous capacity of soil, especially when applied in the form of dewatered sludge cake. Biosolids reduce runoff and increase surface retention of rain water. Organic nitrogen in sludge is much less likely to cause ground water pollution than chemical nitrogen fertilizer. The application of sewage sludge to agricultural land is the best

way of recycling the nutrients present in it. Therefore, sewage sludge may be considered an important biological resource for sustainable agriculture. It produces favorable plant yield responses, when used as an organic fertilizer.

The only drawback in the use of sewage sludge on agricultural land is its pollutant load (including heavy metals, organic compounds, pharmaceuticals and pathogens). Potentially toxic elements, is a general term for wide range of metals that originate in sewage, such as cadmium, copper, nickel, lead, zinc, mercury and chromium. The metals are concentrated in the sludge as a result of their association with settable solids during primary and secondary treatment process. Research on land application of sewage sludge has mainly focused on its role in introduction of heavy metals in the food chain. However, it has been shown that sewage sludge application at recommended rates increased microbial activity in soil and tied up the heavy metals making them unavailable to plant and soil. Another factor which needs careful attention regarding the use of sewage sludge/biosolids is prevalence of pathogens. It contains pathogenic bacteria, viruses and protozoa along with other parasitic helminthes, which can give rise potential health hazards to human, animals and plants. Salmonella and Taenia were identified as the greatest concern and risk to health from microbes in sewage sludge applied to land. The number of pathogenic and parasitic organisms in sludge can be significantly reduced before application to land by appropriate sludge treatment and potential health hazard is further reduced by the effect of climate, soil micro- organism and time after the sludge is applied to the soil.

Information on all these aspects in Pakistan and many under developed countries is limited and scanty. There- fore, this review paper focuses discussion on these important issues so that conclusions can be drawn as how for the sewage sludge is useful in sustaining soil quality and agricultural productivity.

2. Characterization of Sewage Sludge

There is an interesting trend in the agricultural application of sewage sludge obtained from waste water treatment plant due to the possibility of recycling valuable components: organic matter, N, P and other plant nutrients. Characterization of sewage sludge is extremely important prior to sludge disposal or application to farm land because there is a risk of toxic elements accumulation in soil. Moreover, there is potential health hazard due to pathogens in the sewage sludge. The content of the sewage sludge will depend on the original pollution load of the treated water, treatment process applied to waste water and sludge. Sludge treatment affects its composition. Examples of effective sludge treatment processes are presented in Table 1 and various types of sludge used in European countries are given in Table 3.

2.1 Fertility Parameters of Sewage Sludge

2.1.1 Organic Matter and Major Nutrients

Organic matter content and major nutrients were found to be quite high in sludge (Table 3). These are the parameters which are considered essential for enhancing soil fertility/quality and sustaining soil productivity.

Table 1. Effective sludge treatment processes.

Process	Descriptions
Sludge pasteurization	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.
Mesophilic anaerobic digestion	Mean retention period of at least 12 days primary digestion in temperature range 35°C ± 3°C followed in each case by a secondary stage which provides a mean retention period of at least 14 days.
Thermopile aerobic digestion	Mean retention period of at least 7 days digestion. All sludges are to be subjected to a minimum of 55°C for a period of at least 4 hours.

Composting (windows or aerated piles)	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
Lime stabilization of liquid sludge	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.
Liquid storage	Storage of untreated liquid sludge for a minimum period of 3 months.
Dewatering and storage	Conditioning of untreated sludge with lime or other coagulants followed by dewatering and storage of the cake for minimum period of 3 months if sludge has been subjected to primary mesophilic anaerobic digestion, storage to be a minimum period of14 days.

Table 2. Organic matter content and major nutrients in sewage sludge.

Sewage sludge	Method of production and some important characteristics
Liquid sludge	It is produced by sedimentation of screened sewage and contain between 2% and 7% dry solid. Up to 75% of the solid fraction is organic matter.
Untreated sewage cake	The sludge cake is formed by dewatering of liquid sludge and has a consistency similar to soil. Microbiologically, untreated cake is comparable to farm yard manure.
Conventionally treated sludge	The sludge is subjected to digestion to ensure a 99% reduction in microbiological content.
Enhanced treated sludge	The sludge is treated through various processes, which eliminate the pathogen altogether. Techniques include drying of sludge to form granules (98% dry solid), lime pasteurization or digestion, followed by heat treatment.
Composted sludge	Dewatered undigested sludge composts most readily. Composted sludge is odorless friable soil like material. Cereal straw or any other agent is added to the sludge to enhance aeration. The availability of N in the composted
Lime treated sludge	Undigested sludge cake is mixed with lime or waste lime materials in controlled condition to produce friable and easily handle able product. The pH of the product is high which throw off ammonia reducing N content and availability of P.

Table 3. Different types of sludge used in Europe.

Fertility parameters	Pakistan	India
Organic matter (mg·kg–1)	19,400	-
Total nitrogen (mg·kg–1)	16,000	15,400 -
Available N (mg·kg–1)	5200	4600 -
Available P (mg·kg–1)	70	44 - 60
Available K (mg·kg–1)	288	290 - 410

2.1.2 Micronutrients and Heavy Metals

The issue of micro-nutrient and heavy metal concentration in sewage sludge needs careful attention for its use in agriculture. If the concentration of heavy metals is high in the sewage sludge then its continuous use year after year may result in toxic accumulation of heavy metals in the soil, which may have phototoxic effects on various cereals, vegetables, fruits, pastures, and fodder crops. Consumption of these commodities by human

beings and animals can cause health hazards to them. It is, therefore, essential to determine the heavy metal content of sewage sludge before its recommendation for use in agriculture.

Table 4 gives critical concentration of heavy metals in sewage sludge in different countries. Sewage sludge with heavy metal concentration higher than critical level for a given country is not permitted to be used as organic fertilizer for that country. In general, Germany is stricter than United States and European member states with regard to critical levels as shown by the lower values imposed by Germany. Heavy metal ranges in sewage sludges of European member states (Table 4) are comparatively lower than critical level adopted by them. In India the heavy metal ranges were higher than ranges in the European member states (Table 5). However, these values were either lower or closer to those mentioned in Table 4.

Table 4. Critical levels of heavy metals (mg·kg–1) in sewage sludge.

Micronutrient/heavy metals	Range in the European	Range in India	Pakistan
As	-	8 - 23	-
Fe	-	-	250
Mn	-	-	210
Cu	39 - 361	-	202
Zn	142 - 2000	-	640
Cd	0.4 - 3.8	2 - 9	-
Cr	16 - 275	66 -	-
Hg	0.3 – 3	7 - 32	-
Ni	9 – 90	12 - 596	-
Pb	13 - 221	26 - 154	-

Table 5. Micronutrients and heavy metals in sewage sludge.

Heavy metal	86/278/EEC	Country	EC Directiv	
	Japan	US	Germany	
Arsenic	75	-	50	-
Cadmium	85	10	5	20 - 40
Chromium	3000	900	-	1000 - 1750
Copper	4300	800	-	1000 - 1750
Lead	840	900	-	750 - 1200
Mercury	57	8	2	16 - 25
Nickle	420	100	-	300 - 400
Zinc	7500	2500	-	2500 - 4000

2.2 Microbial Pathogens in Sewage Sludge

Microbial analysis of the sewage sludge revealed that sewage sludge contained wide range of microbial pathogens (Tables 6 and **7**). Since the sludge under discussion was from municipal channels, therefore, main source of pathogens in sewage sludge is believed to be human faces. Treatment of the sewage sludge is, therefore, extremely essential for its use in agriculture in order to avoid health risks

Table 6. Microbial contaminations in sewage sludge, D. I. Khan, Pakistan.

Bacteria	Fungi
Salmonella spp.	Aspergillus spp.
Escherichia coli	Alternaria spp.
Staphylococcus aureus	Geotrichum spp.
Proteus spp.	Mucor spp.
Pseudomonas spp.	Rhizopus spp.
Streptococcus spp.	Penicillium spp.
Bacillus subtilis	

Table 7. Pathogens found in municipal wastewater and sewage sludge.

Bacteria	Viruses	Protozoa	Fungi
Salmonella spp.	Poliovirus	Cryptosporidium	Aspergillus
Shigella spp.	Coxsackievirus	Entamoeba histolytica	
Yersinia spp.	Echovirus	Giardia lamblia	
Vibrio cholerae	Hepatitis A virus	Balantidium coli	
Campylobacter jejuni	Rotavirus	Toxoplasma gondii	
Escherichia coli (pathogenic	Human caliciviruses	Helminths worms	
Clostridium perfringens	Reovirus	Ascaris lumbricoides	
Legionella pneumophila	Hepatitis B, C & E virus	Trichuris trichiura	
Listeria monocytogenes	ASTROVIRUSES	Toxocara canis	
Staphylococcus aureus	Adenoviruses	Taenia solium	
Leptospira	Necator americanus		
Icterohaemorrhagiae	Hymenolepis nana		

3. Environmental Implication of Sewage Sludge Used in Agriculture

3.1 Impact on Soil Quality and Fertility

Microbial activities are vital for maintaining soil quality and soil fertility. Sewage sludge has the potential to enhance soil productivity because it contains high organic matter and plant nutrient content. At the same time, sewage sludge can pose a serious threat to human health and ecosystem because of heavy metals and toxic organic compounds. Research on the land application of sewage sludge has mainly focused on its role in the introduction of heavy metals in the food chain. There is limited information as how sewage sludge application can influence soil microbial and biochemical characteristics with respect to maintaining soil quality.

The effects of heavy metals on soil microbial community with emphasis on specific microbial activities have been well documented. Generally the application of low metal sludge have beneficial effects on microbial biomass, organic carbon and on soil microbial activity, whereas higher heavy metal contamination of soils resulted in considerable decrease in biomass carbon, soil microbial biomass level and activities of soil micro organism. This could have permanent adverse effects on soil quality. Some researchers investigated the effect of sewage sludge application on biological and biochemical properties of soil on receiving single and multiple applications of 0, 50 and 100 tons of sludge ha–1. Sludge application significantly increased the amount of microbial biomass in the soil. The biomass N content was uncharacteristically low, resulting in a mean microbial biomass C:N ratio of 36:1. Despite the wide C:N ratio, sludge application enhanced N mineralization potential of soil. Sludge application somewhat increased activities of important soil enzyme (arylsulfatase, acid phosphatase, and alkaline phosphatase). Highest rate of sludge application (200 t·ha–1) was found to significantly reduce functional diversity of soil community. Although sludge application resulted in a reduction of diversity of the microbial population, overall size of the soil microbial biomass and its inherent mineralization potential were unchanged or increased. Manguiat also reported that sewage application did not affect the mineralization of soil organic nitrogen.

Degradation of the organic matter applied in sludge increases the available fraction of nutrients e.g. nitrogen and phosphorus. Application of sewage sludge at a rate of 200 t·ha–1 increased the total nitrogen of soil aggregates by 57% and available phosphorus by 64.2%. Phosphorus and nitrogen are released more slowly through degradation of organic matter than in case of inorganic fertilizers and, therefore, the compounds are

avail- able for longer period. Organic matters in the sludge mainly consist of soluble matter with a small amount of lignin and cellulose that contribute to its composition. That is why the organic matter within the sludge has the potential to mineralize relatively quickly. This potential rapid degradation could lead to a peak in nitrate and phosphorus levels within the soil.

3.2 Impact on Soil Physical Properties

Sewage sludge is a rich source of organic matter. Organic content of sludge in urban sewage is generally high, usually more than 50% of dry matter. Addition of organic matter in the form of sewage sludge will have pro- found effect on soil physical properties and positive soil conditioning effect on most soils. The improved aeration and drainage following sludge amendments can have indirect effects on soil-plant relationships of heavy metals through affecting growth. Effects of sewage sludge/biosolids on soil physical properties such as in- creased soil aggregate formation and stability may be greater than for animal manures due to stability of organic compounds in biosolids. Improved water infiltration is important especially on upland areas where the top soil is shallow and low in organic matter due to soil removal by erosion and grading in terrace formation. Increasing rate of sewage sludge for growing wheat de- creased the bulk density and increased total porosity. In several other studies on agricultural use of amendments consistently showed decrease in the bulk density and penetration resistance with increasing rates of amendment. Reported decreases in bulk density are attributed to increase in aggregate stability and total porosity. Addition of sludge to sandy loam soil in- creased soil aggregates stability by 41% while addition to clay had no significant effect. It also increased the water holding capacity of soil. Top soil available capacity was increased with increasing rates of sludge application. Improvement in soil physical properties will result in increased soil filtration rate, reduction in surface run off and water erosion. The foregoing discussion leads to conclusion that use of biosolids on farm land definitely improves soil physical conditions which is considered extremely essential in sustaining soil productivity.

3.3 Impact on Soil Microbial Properties

In general, addition of organic manure in the form of sewage sludge will increase soil microbial activities, their population and microbial biomass. Consequently the soil life goes through a considerable changing. Application of sludge containing low concentration of heavy metals improved soil microbial activities. However, elevated metal concentrations have been shown to reduce soil microbial biomass levels, inhibit nitrogen fixation by both free living and symbiotic micro-organisms and reduce enzyme activities. Since in calcareous alkaline soils metal get fixed into the soil, therefore, any adverse effect on microbial biomass will be temporary. Ultimately the microbial population/biomass will increase and their activities will enhance. High levels of sludge application (200 ton·ha–1) significantly reduced the functional diversity of soil community but overall size of the soil microbial biomass and its inherent mineralization potential were either unchanged or increased.

3.4 Impact of on Soil Chemical Characteristics

Addition of sewage sludge to an agricultural soil will increase organic matter content in the soil, which leads to production of humic and carbonic acids that play a fundamental role in conditioning soil properties. These acids in calcareous soils will lower the soil pH. In an experiment conducted on calcareous soil, increasing rates of sewage sludge (up to 100 t·ha–1) only after one year reduced soil pH from 8.2 to 8.0. Humic substances have high caution exchange sites. Thus addition of sewage sludge to soil with low caution exchange capacity over period will increase organic matter, which ultimately increases the caution exchange capacity of the soil. Humic substances extracted from sewage sludge strongly interact with pesticides to speed up their biodegradation, and with metal ions influence their transport and plant accessibility. They also act as a potential source of nutrients for plants in addition to their ability to buffer soil pH and xenobiotic organic molecule retention. Moreover, there is high percentage of nitrogen content bound by humic like substances in sewage sludge and compost which is one of the main criterions of usefulness of sew- age sludge compost for agricultural purposes. A better overall decomposition process of sewage sludge is possible through better accessibility of the substrate component for microbiological conversion and application of new types of microorganisms, such as hyperthermophilic microorganisms or genetically modified microorganisms which may be an interesting research for the treatment of sewage sludge in the future. Sewage sludge decomposition is essential because noncomposted or immature

compost applied to agricultural soils may cause phytotoxicity to plants, nitrogen and oxygen deficiency and adversely affect the environment.

3.5 Impact on Availability of Heavy Metals and Pollution

Almost all types of sewage sludge contain heavy metals. Heavy metals such as cadmium, copper, nickel, lead, zinc, mercury, and chromium which originate in sewage are regarded as potentially toxic elements. With the application of sewage sludge, heavy metals also enter the soil by atmospheric deposition from both natural and anthropogenic sources. Metals may be removed from the soil through plant uptake, wind/water erosion, leaching and runoff. On certain soils e.g. copper deficient soils, heavy metals in sewage sludge can correct element deficiency. When sewage sludge is applied to soil, equilibrium between the soil and liquid phase of the heavy metal applied with the sludge will be established. Strong binding between components of soil and heavy metals from sewage sludge causes heavy metals to be retained in the upper layers, where they are applied with concentration decreasing rapidly with depth. It has been found that mean layers of soil enriched in heavy metals are 0 - 15 cm and 15 - 40 cm, approximately equivalent to depth of incorporation of the sludge. Incorporation of sludge into agricultural soils in UK would rarely exceed 30 cm, the depth of sampling. Factors that influence the movement of metal within the soil include soil pH, caution exchange capacity (CEC), organic matter content, temperature, soil humidity, soil structure and soil type. The most important factor controlling the movement of metals in soil is pH and it is considered to be the most effective and rapid method of controlling the bioavailability of heavy metals in sludge treated soil. Soil pH influences the precipitation and dissolution of insoluble hydroxide and formation of mineral organic complexes. Increasing the pH also increases adsorption of heavy metals on clay and organic matter. SNIFFER based on scientific evidence suggested that there should be single figure metal limit for soils in the pH range 5 - 7 and that sludge should not be applied to agricultural soils with pH lower than 5. Higher soil metal limits could be safely set for soil of pH greater than 7 containing at least 5% calcium carbonate. Majority of Pakistan and other countries, soils under arid environment are calcareous alkaline with pH ranging from 7.5 to 10 or even more and lime content ranging from 5% to 20%. On arid lands where rain fall varies from 150 to 250 mm, lime contents may be as high as 40%. Therefore, the use of sewage sludge with moderate level would not be a problem because the metals will be precipitated/ adsorbed on the clay particle.

Organic matter of the sewage sludge is other important factor which controls the bioavailability of heavy metals in soil. It is a very important adsorptive medium for trace metals in the soil. Soluble organic matter from sludge has two groups of exchange sites, one binding Ca, Mg, Zn, Ni, Co, Mn, Cd, Pb, and Fe and the other binding only Cu, Pb, and H. Free metal activity in soil solution was found to be significantly reduced by organic ligands.

Bioavailability of Cd is restricted in calcareous soil. This is likely to be due to a combination of chemisorptions, precipitation of $CdCO_3$ and competition with Ca^{2+} ion for absorption sites on plant roots. The labile fraction of heavy metals in soil is the most important for toxicity to plants. It is, therefore, crucial to reduce this fraction in sewage sludge contaminated soil to decrease their negative effects. Application of 2% (w/w) Na benovite, Ca benovite and phosphatic fertilizers especially Novaphos at 0.05% (w/w) strongly reduced bioavailability of heavy metals in wheat plant. In Australia the risk of heavy metals present in the sewage sludge regarding their adverse effects on the environment and food chain (when used in agriculture ac- cording to the best practices/methods) is not greater than conventional fertilizer (bearing heavy metals). For example, single super phosphate fertilizer sold in Australia contains 3.4 to 24.4 mg·kg–1 cadmium. This concludes that there is a little or no danger of accumulation of heavy metals due to application of sewage sludge to high pH calcareous soil in arid and semiarid regions of the country. However, despite undisputable advantages obtained from the application of sewage sludge in agriculture, it may involve some serious threat in the form of organic pollutants (potentially toxic organic compounds in sewage sludge). It is particularly important, due to its diversified effects on living organisms (mutagenic effect, carcinogenic effect, endocrine disrupting effect). Organic pollutants and their potential threats are identified with biological tests. The estimation of phytotoxicity with biological tests is extremely important due to its frequent utilization for natural purposes. The application of phytotoxicity tests will evaluate the applicability of sewage sludge for agricultural or soil reclamation purposes, and also to identify potential threats for the environment and human health. Research results revealed that level of phytotoxicity depends on soil type, species of plants grown, and nature of sewage sludge. Some researchers have reported that

sewage sludge can be used as biomass resource for the production of energy (heat, electricity, or biofuel) which is then used as energy source in the production of cement or building materials. In these processes, the toxic organics are destructed and the heavy metals are immobilized in the ash or cement.

3.6 Impact on Pathogens in Soil

The biggest objection on the use of sewage sludge in agriculture is accumulation of pathogenic organisms in soil. Sewage sludge contains pathogenic bacteria, viruses and protozoa, which can give rise to potential hazards to the health of human, animals and plants. The number of pathogenic and parasitic organisms in sewage sludge can be significantly reduced before application to the land by appropriate sludge treatment. Pathogenic micro- organism can be eliminated by the use of sewage sludge such as untreated sewage cake, conventionally and enhanced treated and composted sludge. Irradiation is another approach for decontaminating sewage sludge. It involves exposure to gamma radiation. The gamma radiation induces ionization of biological tissues and subsequently cell protoplasm is damaged, hence, the pathogen is inactivated. Once applied to land, pathogens are removed from the sewage sludge by filtration, adsorption by soil constituents and natural die off.

Pathogens survival in the soil is dependent on numerous direct and indirect factors. Indirect factors include climatic factors (e.g. sunlight, temperature, desiccation or pH), characteristics of soil (e.g. texture and moisture), quantity of sludge, its organic content and presence of competing and predating micro-organism. Direct factors include the biological characteristics of pathogens in question especially the form in which it is applied to soil e.g. spore. The main factors and environmental conditions influencing the pathogen survival are summarized in Table 8.

Depending on the conditions and organisms them-selves, survival period vary from a few days to several years in some cases. Parasites, eggs or cysts are the longer survivors, surviving one to two years in certain favorable circumstances. Pathogen survival times are longest in moist, cold soils and shortest in dry warm soils. About 68% of Pakistan falls in arid and semi arid region where summer temperatures range from 40°C - 52°C and rain fall is low. Under these agro-environmental conditions, pathogen survival will be in days. Another most important factor influencing the survival of pathogen in soil is competition with existing micro flora. According to research report, newly added micro-organisms may persist for much longer in soil with low microbial activity. However addition of large quantities of sewage sludge to soil is likely to enhance microbial activity in low activity soil thus reducing the survival of pathogens within the soil environment as described in Table 8.

Table 8. Factors influencing pathogen decay in sludge amended soil.

Factors	Comments
Temperature	10°C rise increased die-off two fold Longer survival in winter than in summer
Moisture content	Decreasing moisture content increased die-off
Water holding capacity	Poor water holding capacity decreased survival
Soil water suction	Maximum survival in saturated soil
Application method	Conflicting report for die-off rates for sludge applied to soil surface and incorporated sludge Injected sludge may protect organisms Disking may re-contaminate land
pH	Shorter survival times in acid soils (pH 3 - 5)
Low nutrient availability and competing flora	Soil is a hostile environment for pathogen survival

4. Sewage Sludge as Biological Resource for Sustainable Agriculture

There is an increasing interest in agricultural application of sewage sludge obtained from wastewater treatment plants due to possibility of recycling of valuable components such as organic matter, N, P and other plant nutrients. Since sewage sludge contains substantial amounts of nitrogen and phosphorus, it can be an effective fertilizer replacement for these important nutrients. In addition to these attributes, it may conserve organic matter and provide an opportunity for its beneficial re-use as a resource in agriculture and reclamation in preference to its disposal. Moreover, organic matter in soils of arid and semi arid regions is low due to rapid oxidation. Maintaining adequate organic matter content is essential for maintaining soil fertility and productivity. Composting municipal solid wastes and sewage sludge is a good way to reduce the amount of wastes generated in densely populated areas and the agronomic use of compost manure is one method to increase organic matter. Composting processes are expected to lower the availability of metals in amended soil.

Metals are strongly bound to the compost substance and organic matter, limiting their solubility and potential bioavailability in soil which may protect the soil and environment from potentially negative impacts caused by long-term accumulation of heavy metals in soil. Application of compost and sewage sludge have been shown to have many advantages including provision of a whole array of nutrients to soil, increasing beneficial soil organism, reducing plant pathogen and improving water holding capacity. Besides these advantages, sewage sludge will build and maintain higher soil organic matter levels that will sequester carbon and mitigate greenhouse gas emissions.

4.1 Use of Sewage Sludge for Crop Husbandry

Being an important organic fertilizer, sewage sludge is used for crop production in both the developed and developing countries of the world. However, mixed crop responses to sludge application have been reported. In a study on wheat both straw and grain yield increased with increasing rates of sewage sludge application up to 40 t·ha–1. Above this level there were declining trends both in straw and grain yields (Table 9). Regression analysis also revealed quadratic trends regarding straw and grain yield in response to increasing sewage sludge level (For straw, $Y = 5.8 + 0.128x - 0.001x2$, $R2 = 0.947$; for grain yield, $Y = 3.21 + 0.095x - 0.000x2$, $R2 = 0.837$). Similarly, Mn, Fe and Zn concentration in leaf tissues (at boot stage) increased significantly with an increasing rate of sewage sludge from 10 to 40 t·ha–1 **(**Table 10). Cu concentration was higher when sewage sludge was applied at the rate of 10 to 20 t·ha–1. Application of 20 ton of sewage sludge along with half of the recommended dose of NPK produced highest grain yield in wheat, however, it significantly reduced Mn, Fe, and Zn concentration in leaf tissue. In Philippine, sewage sludge application increased the yield of upland rice whether applied alone or in combination with N fertilizer. In Hawaii aerobically digested sludge increased maize biomass whereas two undigested sludge's reduced it. At higher rates phytotoxicity resulted from sludge application on roots containing reducible Mn nodules. Adequate supplies of Ca and Zn appeared to reduce Mn toxicity.

Table 9. Effect of different levels of sewage sludge on wheat yield.

Sewage	Straw yield	Grain yield
0	5.80 g	3.21 g
10	7.22 f	4.22 f
20	8.00 e	5.22 c
40	9.82 a	6.15 a
60	9.40 b	5.65 b
80	9.30 c	5.20 d
100	8.70 d	5.10 e

Table 10. Effect of sewage sludge application on heavy metal concentration in wheat leaf tissues and grain yield.

Treatments	Heavy metals in wheat leaf tissue				
	Cu	Mn	Fe	Zn	Grain yield t·ha–1
Control	8.98 c	59.8 e	91.8 e	22.9 e	1.67 e
*SS@ 10 t·ha–1	12.53 a	82.3 c	123.7 d	35.1 d	2.17 d
SS@ 20 t·ha–1	10.65 a	91.2 b	197.0 c	37.4 c	2.30 c
SS@ 40 t·ha–1	9.22 bc	98.3 a	245.5 a	45.6 a	2.61 b
SS@ 20 t·ha–1 + 1/2 NPK (recommended)	10.92 ab	78.3 d	242.0 b	42.2 b	3.17 a

In UK, crop yields were not significantly affected in 60% of the cases studied, but in 26% of the cases liquid sludge application resulted in significantly increased crop yield, probably due to beneficial effects on soil structure. Reductions in wheat grain yield, from 6% - 10%, were noted on the clay soils treated with bed-dried sludge. However, yield reduction was not thought to be due to metals but most likely explanation was lodging of the crop as a result of excessive nitrogen in the soil. In- creases in metal concentrations in the soil due to sludge application produced significant increases in Cd, Ni, Cu, and Zn concentrations in the edible portion of the most crops grown; wheat, potato, and rye grass. In most cases there was no significant increase of Pb in crop tissue in relation to Pb in the soil from sludge application, suggesting that lead is relatively unavailable to crops from the soil. The availability of metals to crops was found to be lower in soil treated with bed-dried sludge cake compared with liquid sludge. Treated sludge can be applied to growing cereal crops without any constraint. There are no constraints when treated sludge is applied before planting such as cereals, fodder and sugar beet etc. However untreated sludge should be applied or injected into the soil before planting crops.

4.2 Use of Sewage Sludge for Fruit and Vegetable Production

Fruit and vegetable are consumed by everybody. Use of organic manures for their production is an important in- put. Fruits and vegetables production need to be further enhanced in view of rapidly growing demographic pressure. Organic manures are not enough to meet the requirements of fruit and vegetable production. Sewage sludge being a valuable input can be used for fruit and vegetable production in view of its high organic matter content and rich macro and micro nutrients. However extreme care is to be taken to avoid the entry of the heavy metals and other organic compounds in the food chain.

Positive effects of sewage sludge on the yield of both summer and winter vegetables have been recorded (Tables 11 and 12). However, yield was the highest when NPK fertilizer was applied at the recommended rate (120-90-60 kg·NPK·ha–1). In Jordan, addition of 40 tons·ha–1 sewage sludge (equivalent to the recommended fertilizer rate) increased lettuce growth. Higher rate further increased the lettuce growth, but it resulted in higher plant heavy metal content. Therefore, addition of 40 tons·ha–1 to calcareous soil was recommended to optimize plant growth and minimize adverse effects on plant and soil quality.

Table 11. Effect of sewage sludge on yield of winter vegetables

Sewage sludge (t·ha–1)	Carrot F.W. t·ha–	Turnips F.W.	Radish F.W. t·ha–
0	5.75d	5.32d	4.49c
25	6.25cd	5.99cd	3.26c
100	7.12bc	6.25cd	4.97c
150	8.18b	7.74b	6.57b
RDF**	12.00a	9.94a	8.10a

Table 12. Effect of sewage sludge on summer vegetables.

Summer vegetable			
Sewage sludge	Tomato	Onion	Summer squash
(t·ha–1)	(t·ha–1)		
0	5.56d	4.43c	12.25d
75	6.12cd	5.20cde	14.9bc
100	6.76cd	5.85bcd	15.5bc
150	8.43b	6.74ab	16.6b
RDF*	11.68a	7.37a	19.8a

In another study, addition of sew- age sludge at 20, 40, 80 t·ha–1 increased lettuce yield, head circle, plant height, leaf number, N, P, K and Mg level to some extent. Leaf Cd concentration increased in sludge treated plots. Sewage sludge application increased organic matter, total N, exchangeable P, exchangeable K, AB-DPTA extractable Mn, Cu, and Cd concentration of top soil. It was concluded that sewage sludge could be an alternative to manure to enrich organic matter, and rectify N, P, Fe and Zn deficiencies in high pH and calcareous soils.

In Spain, findings of study conducted on citrus to assess the potential of using sewage sludge as an alternative to chemical fertilizer, revealed that use of sewage sludge was suitable to fertilize 3 - 4 years old citrus trees. Nitrogen availability was adequate for root uptake and for satisfactory leaf N levels and growth. However one should be cautious regarding the use of sewage sludge for horticultural crops. Sewage sludge must not be applied to growing soft fruits or vegetable crops. The growth of the cauliflower, cabbage and potato from field receiving sewage sludge for long periods was de- pressed and different plant parts showed phytotoxicity symptoms. Vegetables growing near the discharge point contained the maximum amounts of heavy metals which were above toxic limits of these elements, e.g. accumulation of Cr in potato.

4.3 Use of Sewage Sludge in Dairy Pastures

The main potential use of sewage sludge/biosolids is as a fertilizer and/or soil conditioner to improve growth of the dairy pasture and maintain the structure of soil. Sewage sludge supply a range of valuable plant nutrients such as nitrogen, phosphorus, iron, calcium, magnesium and various other macro and micronutrients. Many of these nutrients are also essential component of the healthy diet of a cow for maintaining growth and milk production. Moreover, sewage sludge contains a significant amount of organic matter (approximately 40% - 60%) which improves soil structure by increasing soil aeration and water holding capacity of the soil.

In Australia where sludge cake biosolids were applied at 0, 30, 60 and 120 dry t·ha–1 to sheep grazing pasture, biosolids reduced run off and increased surface retention of rain fall. There was low concentration of metals in the runoff water. Thus there was no concern of the environmental pollution. However NO3 movement was observed up to 50 - 70 cm in sandy red earths [5] when biosolids were used for dairy pastures. They must be injected or incorporated into the soil by ploughing. This would minimize the risk of pathogen intake in animals directly ingesting the biosolids in large quantities.

With holding periods for which animals should not be allowed to graze on pasture treated with sewage sludge should be adhered too to minimize pathogen and chemical contamination risks. This include all livestock from the time of biosolids application for at least 4 weeks, and for lactating stock and new born animals at least 12 weeks. Treated sludge should not be applied to growing turf within 3 months of harvesting. Other practices that reduce the chances of pathogens being transferred in to the milk are: that biosolids should not be applied to muddy/water logged pasture; injection method of biosolids application into the soil and/or incorporation/ ploughing of biosolid in to the soil should be encouraged.

4.4 Use of Sewage Sludge in Forestry

The overall goal of sewage sludge addition to forestry is to improve physical, chemical and biological properties of soil and fertility status for creating more favorable conditions for establishment of vegetation or improve plant growth in the existing forests. Untreated sludge cake is mostly used in the forestry. When considering reforestation, land spreading may be carried out prior to planting. In intensive forestry production sludge application may be performed just after sowing, thinning, or clear filling. In established forest, sludge application could potentially occur throughout the year, if good practices are observed and local conditions are

acceptable. Application of sewage sludge in excess can add excessive amount of nutrients to soil, which can directly dam- age the trees, and create risk to the environment. Excessive use of sludge can also cause an increase in the proliferation of weeds.

5. Conclusion

On the basis of above review it can be concluded that sewage sludge is very important biological organic fertilizer/soil conditioner for sustainable agriculture. It improves organic matter status of the soil. It also adds macro and micronutrients to the soil. Improvement in organic matter content in soil helps in improving soil physical conditions, rejuvenating soil health and stimulating biological activity. Generally positive effects of application of sewage sludge have been reported on cereals, vegetable and horticultural plants, pastures and forestry. Regarding the danger of toxic accumulation of heavy metals in soil it is well documented that the heavy metals and micronutrients are rendered unavailable due to precipitation in calcareous alkaline soils. Also these metals can be immobilized due to organic materials in the sewage sludge through formation of stable complexes. In other words, organic matter in sewage sludge reduces the negative environmental effects of heavy metals and other pollutants by binding contaminants. Higher level of soil organic matter can sequester carbon and mitigate greenhouse gas emissions. Regarding the pathogen in sewage sludge, their number can be significantly reduced before application to soil by appropriate sludge treatments. An enhanced microbial activity due to addition of sewage sludge reduces the survival of the pathogens in soil. Application of sewage sludge to dry soil in warmer region of the countries, 2 to 3 months ahead of seeding the crop will eliminate most of the pathogens from the soil. Therefore, use of sewage sludge in agriculture will be appropriate and beneficial, if applied according to appropriate guidelines to minimize environmental and ecological damage and maximize potential benefits for sustained agricultural productivity. However, sewage sludge prior to use in agriculture must be subjected to evaluation tests for determining the basic physicochemical properties, content of pollutants or pathogenic bacteria, and also ecotoxicological properties in order to avoid the risk of potential threats for the environment and for human health.

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