Heavy Metals Concentrations in Biosolids of Al-Bireh Sewage Treatment Plant and Assessment of Biosolids Application Impacts on Crop Growth and Productivity

By

Nasser M. Samara

(1045080)

Supervisor

Dr. Rashed Al-Sa'ed

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This thesis was prepared under the supervision of Dr. Rashed Al-Sa'ed and has been approved by all members of the Examination Committee.

Dr. Rashed Al-Sa'ed

(Chairman of the Committee) ....

Dr. Jamil Harb

(Member) ....

Dr. Mustafa Khamis

(Member) ....

The findings, interpretations and conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of the individual members of the M.Sc. Committee or views of their respective employers.

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ABSTRACT

The aim of this study was to investigate the concentrations of heavy metals in biosolids (stabilized sewage sludge) of Al Bireh Wastewater treatment plant (AWWTP). The study has looked at certain types of heavy metals which could inter to the AWWTP through industrial and domestic discharges. The specific objective of the study was to measure the concentrations of heavy metals in biosolids produced by AWWTP to evaluate its potential impacts on plant growth and production if applied to agricultural land.

To achieve these objectives, 10 composite samples of biosolids were collected from AWWTP thickener tank during a period of 6 months. Samples were handled and analyzed according to the standard methods for analyzing water and wastewater using ICP-AES analysis method for heavy metals determination. Biosolids samples were initially characterized to identify its primary physiochemical characteristics (pH, EC, TS, TSS, and TVSS). Laboratory testing to analyze heavy metals (Zn, Cu, Ni, Cr, Cd, Pb, As), in addition to Boron (B), were performed for each sample using the ICP-AES instrument applying the standard methods for water and wastewater analysis. Analysis results indicated that the maximum concentrations of analyzed metals found were 1150.3, 411.4, 115.7, 232.9, 94.0, and 62.6 mg/kg dry weight for Zn, Cu, Ni, Cr, Cd, Pb, while As was not detected in any of analyzed samples. Moreover, the maximum concentration for Boron was 58.8 mg/kg. These concentration values did not exceed the maximum permissible concentration limits in both EPA and EU standards for biosolids land application. Moreover, these values are lower than the maximum permissible concentrations (except for Nickel), for biosolids application if compared to the Israeli standards. Accordingly, these results indicate that biosolids of AWWTP can be utilized for land application in terms of heavy metals concentration limits, although there is the necessity to follow some restrictions and preventions related to soil, crop types and any potential impacts on surrounding environment and natural resources.

Of equal importance, the concentrations of heavy metals in wastewater influent and the treated effluent of AWWTP were also investigated by performing the ICP –AES analysis for 8 samples of each type. It was found that the maximum concentrations of Zn, Cu, Ni, and Cr in treated effluent were 1480, 207.6, 47.6, and 89.4 µg/l respectively, while Cd, Pb, and As were not detected in any of the analyzed effluent samples. These values are below the permissible limits of the Palestinian standards for effluent quality. Moreover, mass balance calculations have been also performed to quantify the average daily loads entering and exiting the treatment plant, and this has provided an approximate assessment of retained quantities from each metal in disposed biosolids.

Biosolids have been also assessed in terms of its potential impact on crop productivity if applied during the initial land preparation and mixed with soil before growing. For this purposes, four loading rates of dried biosolids of AWWTP (0, 20, 40, 60 tons /ha) were applied to a pilot scale plots of 0.25 m^2 with 4 replicates for each treatment. A commonly open field grown fodder crop in Palestine, Egyptian clover (*Trifolium alexandrium* L), was used to investigate the impact of biosolids application rates on plant growth and productivity. Plant growth indicators have been measured and recorded. A significant positive impact on plant growth and production was obtained in the treatments compared to control treatment. Furthermore, a significant difference in plant growth and productivity was obtained in loading rates of 40 and 60 tons/ha compared to the loading rate of 20 tons /ha. However, no significant differences were recorded regarding plant growth and productivity between loading rates of 40 and 60 tons/ha. In addition to this, no visual symptoms were appeared for heavy metals toxicity on plant parts in all treatments during the whole plant growth period.

The results of this study are only valid for short term crop cycles and do not consider the existence of other organic and inorganic pollutants. However, the long term impact of biosolids application and the impact of other toxic organic and inorganic pollutants should be subjected to further investigation.

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List of abbreviations

AAS	Atomic absorption spectrometry
AWWTP	Al Bireh wastewater treatment plant
BOD	Biochemical oxygen demand
CWA	Clean Water Act
DAP	Di ammonium phosphate
DM	Dry matter
Dunum	1000 m^2
DY	Dry yield
EC	Electrical conductivity
EEC	European economic commission
EPA	Environmental Protection Agency
EU	European Union
FAO	Food and Agricultural Organization of the United nations
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
ha	Hectares
HM	Heavy metals
ICAP	Inductively coupled argon plasma
IDL	Instrument detection limit
ICP-AES	Inductively Coupled Plasma - Atomic Emission Spectrometry
NTU	Nephelometric turbidity units
ppb	Parts per billion
ppm	Parts per million
PWA	Palestinian Water Authority
TS	Total solids
TDS	Total dissolved solids
TSS	Total suspended solids
TVS	Total volatile solids
TFS	Total fixed solids
TVSS	Total volatile suspended solids
UNDP	United Nations Development Program
WHO	World Health organization
WW	Wastewater
WWTP	Wastewater treatment plant

CHAPTER 1

INTRODUCTION

1.1 Background

Most wastewater treatment processes produce biosolids (sludge), which has to be disposed off. Conventional secondary sewage treatment plants typically generate the primary sludge in the primary sedimentation stage, and the secondary biological biosolids (sewage 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 disposed alone or after mixing with the primary sludge, if no utilization procedures are adopted. Approximately one half of the costs of operating secondary sewage treatment plants can be associated with sludge treatment and disposal. Land application of raw or treated sewage sludge can reduce significantly the sludge disposal cost component of sewage treatment as well as providing a large part of the nitrogen and phosphorus requirements of various crops. Moreover, biosolids contain significant quantities of organic matter, moisture, nutrients and trace elements, and as such are increasingly being viewed as a resource for agricultural and municipal sectors.

However, urban sewerage systems transport also industrial effluents and storm-water runoff from roads and other paved areas which are frequently discharged into sewers. Thus, biosolids will contain, in addition to organic waste material, traces of many pollutants. Some of these substances can be toxic to plants, animals and even to humans, which justify the necessity to control these potentially toxic elements and the rate of application to the soil, (Suess, 1985).

Moreover, biosolids also contain pathogenic bacteria, viruses and protozoa along with other parasitic helminths which can give rise to potential hazards to the health of humans, animals and plants. A WHO (1981) report on the risk to health of microbes in biosolids applied to land considered *Salmonellae* and *Taenia* to be of greatest concern. The number of pathogenic and parasitic organisms in biosolids can be significantly reduced before application to the land by appropriate sludge treatment and the potential health risk is further reduced by the effects of climate, soil-microorganisms and time after application to soil. Nevertheless, in the case of certain crops, limitations on planting, grazing and harvesting are necessary.

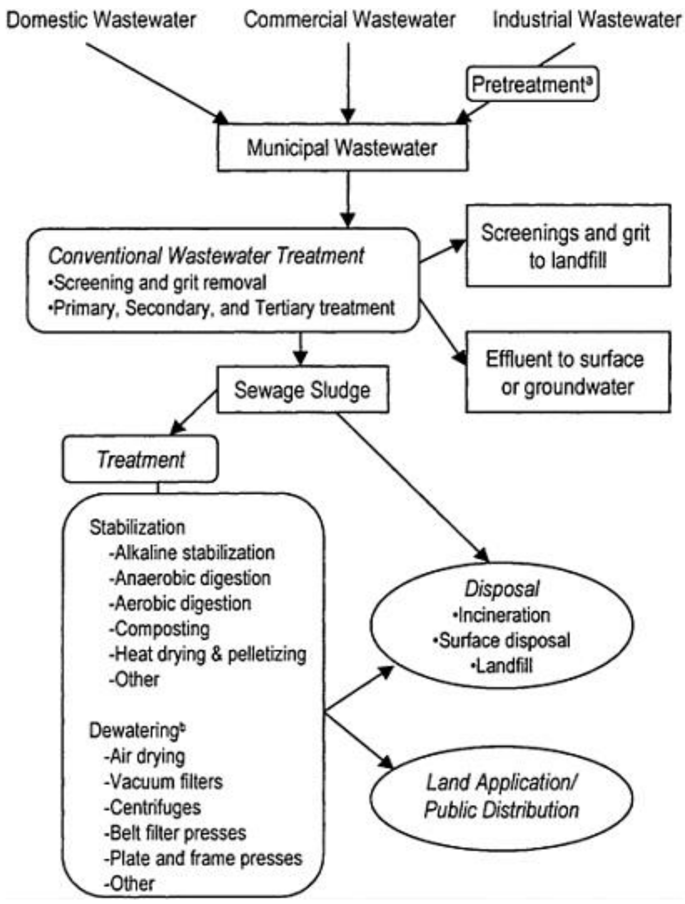

Figure 1-1: Biosolids production. (US national academy of science, 2002)

1.1.1 Heavy Metals in biosolids

Some heavy metals in sewage sludge are micro- nutrients essential for plant growth (e.g., copper, and zinc) and subsequently beneficial to crops. However, like most elements, excess amounts present problems for plant growth. Other heavy metals are not essential for plant or animal nutrition and are toxic to plants, animals and humans at defined concentrations (e.g., arsenic, cadmium, lead, and mercury).

Heavy metals are also relatively immobile in soil, which means they accumulate in the plow layer of the soil and may remain there to indefinite period.

When considering the toxicity of a heavy metal, the route by which the smallest amount of an element can cause harm is used as the limiting concentration. For most heavy metals, this limiting route of exposure falls into one of three categories: plant growth, animal health, or human health (Table 1.1).

Table1.1**:** Heavy metal effects. (Brady and Weil, 1996)

Element	Essential for plant growth	Toxic*
As	No	P, A, **H**
Cd	No	P, A, **H**
Cu	Yes	**P**
Pb	No	A, **H**
Hg	No	A, **H**
Mo	Yes	P, **A**, H
Mi	Yes	**P**, A
Se	No	P, **A**, H
Zn	Yes	**P**, A

*P = plants; A = animals; H = humans.
Bold designates the limiting route of exposure.

Heavy metals in biosolids originate from a number of different sources such as industrial, commercial businesses, domestic household waste (from feces, cleaners, paints, and wear and tear of utensils and equipment), eroding pipes, and runoff from roads and roofs. Over the past few decades the heavy metal content of biosolids has decreased due to the pre-treatment of industrial waste. However, heavy metals in some concentration are still present in biosolids.

The Environmental protection Agency in the United States has specified in its guidelines of biosolids application (40 CFR Part 503), the environmental hazardous indices of heavy metals in biosolids based on different usage and disposal activities as shown in table 1.2.

Table 1.2 Environmental profiles/hazards indices of heavy metals in biosolids :(EPA, 40 CFR PARTS 257, 403 and 503)

Pollutants	Land Application	Landfill	Incineration
As	X	X	X
Cd	X	X	X
Cr	X	X	X
Co	X	X	
Cu	X	X	X
Pb	X	X	X
Hg	X	X	X
Mo	X	X	
Ni	X	X	X
Se	X		
Zn	X		

According to Sorme *et al* (2003), the amounts of different heavy metals can enter the main sewage system up to the treatment plant from different resources depending on many factors. Sorme *et al* (2003) investigated sources of Cd, Cr, Cu, Hg, Ni, Pb and Zn that reached one of the largest wastewater treatment Plants in Sweden.

Table 1.3**:** Main goods and activities that produce heavy metals to the combined sewage system up to the treatment plant (Sorme *et al*, 2003).

Heavy metal	**Potential sources**	
Cd	• Artists paint • Atmospheric deposition • Car washes • Drainage water	• Food • Galvanized materials • Large enterprises • Powdered laundry detergent
Cu	• Brake lining • Car washes • Drainage water • Food • Large enterprises	• Pipes and taps in the tap water system (including drinking water) • Roofs
Hg	• Amalgam in teeth • Amalgam from dentists • Food	• Pipe sediments • Powdered Laundry detergents
Ni	• Chemicals added during wastewater treatment • Car washes • Atmospheric deposition	• Drainage water • Drinking water • Food • Large enterprises
Pb	• Asphalt • Brake lining • Car washes • Atmospheric deposition	• Drainage water • Large enterprises • Pipe sediments
Zn	• Car washes • Drainage water • Chemicals • Food	• Galvanized materials • Large enterprises • Pipes and taps in the tap water system (including drinking water) • Tires

1.1.2 Biosolids application, potential impact and limitations

Apart from those components of concern, sewage sludge also contains significant concentrations of nitrogen, phosphorus and organic matter. The availability of the phosphorus content in the year of application is about 50% and is independent of any prior biosolids treatment. Nitrogen availability is more dependent on biosolids treatment, where untreated liquid biosolids and dewatered treated biosolids releasing nitrogen slowly which benefit the crops over a relatively long period. Liquid an-aerobically-digested biosolids have high ammonia-nitrogen content, which is readily available to plants and can be of particular benefit to grassland. The organic matter in biosolids can improve the water retaining capacity and structure of some soils, especially when applied in the form of dewatered biosolids cake.

Biosolids have been applied worldwide in increasing amounts for this purpose during the recent decades. Organic wastes such as municipal biosolids are usually inexpensive and available locally and could be used as fertilizer to increase yield and to improve soil properties together with legume crops of marginal lands.

When we think about biosolids as a valuable potential resource for land fertility improvement, we must consider the fact that it could contain some potential hazardous additives which should be assessed and avoided before any application of biosolids to soil. The concentrations of potentially toxic elements in arable soils must not exceed certain prudent limits within the normal depth of cultivation. No biosolids should be applied at any site where the soil concentration of toxic metals concentrations exceeds the specific allowable limits which were identified in many established standards. Biosolids application standards are obligatory guidelines that identify the maximum permissible concentrations of the potentially toxic elements in biosolids before land application. As an example, the standards of biosolids application developed by the Israeli Ministry of Environmental Protection for requirements for class A biosolids, which is virtually pasteurized and highly stabilized (Table 1.4). According to the Israeli Ministry of Environmental Protection, the aim is to prevent potential negative impacts on agricultural crops, public health, soil and groundwater.

Table 1.4: Class (A) biosolids application standards (Israeli Ministry of Environmental Protection, 2008)

Metal	**Maximum allowable concentration limits mg/kg total solids**
Cd	20
Cu	600
Ni	90
Pb	200
Zn	2500
Hg	5
Cr	400

The most suitable soils for application of biosolids are those with no inherent limitations on the use of the biosolids nutrients; these soils should have suitably low contents of heavy metals. Moreover, biosolids should not be applied to hydric (wetland) soils, soils prone to flooding, sandy soils, soils having bedrock or water tables at less than 80 cm depth, or to soils located on slopes greater than 12% (Krogmann et al, 2001). According to US-EPA regulations, crops consumed by humans and animals may be grown on land to which biosolids have been applied with certain restrictions based on the class of biosolids. However, the guidelines of Rutgers Cooperative Research and Extension (RCE) in New Jersey-USA suggest that all biosolids and biosolids products be applied in a manner that will avoid direct ingestion of biosolids by animals. Also suggested is that biosolids and biosolids products not to be applied to fruit and vegetable crops due to disagreements related to research, public perception, and liability issues. According to NOFA-NJ (Northeast Organic Farming Association–New Jersey), biosolids and biosolids products cannot be used in certified organic agriculture.

1.1.3 Biosolids types for agricultural use

Biosolids are available in liquid or solid forms (pellet, compost, and advanced alkaline (limestone) stabilized forms). The type of processes used to reduce pathogens often determines the type of material available. The main four forms of utilizable biosolids are:

I. **Liquid biosolids** which have total solids content of less than 8 percent which can be transported and handled as a liquid material.

II. **Dewatered biosolids** which are liquid biosolids that subjected to partial drying through passing the dewatering machines. The solid content will increase to reach up to 25%.

III. **Biosolids compost**: is a relatively stable humus-like material, which is the product of aerobic biological decomposition of biosolids at elevated temperatures.

IV. **Advanced alkaline stabilized biosolids** resulted from treatment process using lime (Calcium oxide), or hydrated lime (Calcium hydroxide).

Other biosolids products include pelletized biosolids, a dry and easy flowing material, resulting from drying biosolids at high temperatures to create a Class (A) biosolids product. Common uses include specialty fertilizer mixes and side dress fertilizer.

1.1.4 Recommended methods and rates of biosolids application

The application rate of biosolids depends on several factors, including if the material is to be used for pH management or nutrient management. Lime stabilized biosolids or advanced alkaline stabilized biosolids should be used as a liming material or as a fertilizer, whichever application rate is lower. In any case, the nutrient value should be accounted for. The maximum application rate should be based on: the fertilizer equivalent of the product with phosphorus or nitrogen level often are the most limiting factors, the fertilizer requirement of the crop to be grown, or the pollutant loading limits, whichever is most stringent.

Biosolids should be applied either by injection or incorporation into the soil by tillage operations such as disking, plowing, or roto-tilling to 12 - 24 cm depth within a maximum of 24hours after application. Incorporation or injection should not be greater than 24 cm deep to allow maximum use of nitrogen by the crop. Biosolids should not remain on the surface of bare soil for more than 24 hours to prevent the loss of nitrogen via ammonia volatization, the odor, and possible loss of biosolids from the site by erosion or surface runoff. Liquid biosolids should be applied in such a manner that there is no ponding or runoff. The application rate to avoid runoff and ponding depends on the solids content of the liquid biosolids and the soil texture. Biosolids should be injected into existing hay, pasture, forage, or turf crops in a manner that avoids biosolids left on the surface or adhering to plants.

Where injection into the soil is used as a vector attraction reduction method given in EPA guidelines 40 CFR Part 503, class A biosolids must be injected within 8 hours of being discharged from the treatment process. Additionally, no liquid biosolids (Class A or Class B) may be left on the surface of the soil 1 hour after injection, and class A biosolids must be incorporated within 8 hours of being discharged from the treatment process. Additionally, the biosolids (Class A or Class B) must be incorporated into the soil within 6 hours of application to or placement on the land (Krogmann et al, 2001).

In each case and according to the USEPA regulations, biosolids should be applied at the most restrictive application rate determined by considering nutrient levels If any sample exceeds the allowable concentrations or application rate, biosolids application could be restricted. Moreover, for nutrients concentrations the plan should specify that biosolids application will not exceed the agronomic rate (plant requirements). Consideration should be given to the time of application, time of planting, crop growth, and various factors, to ensure that the nitrogen in the biosolids is effectively used by the crop. Regarding metals levels, biosolids or material derived from biosolids shall not exceed the ceiling concentrations (according to the EPA regulations), in order to be considered for land application. All biosolids analyses must indicate levels below the ceiling values, i.e., sample results may not be averaged to meet ceiling concentrations. If such levels cannot be maintained, the biosolids shall be disposed at an approved disposal facility or further processed.

1.1.5 Planting, grazing and harvesting constraints

To minimize the potential risk to the health of humans, animals and plants it is necessary to coordinate biosolids applications in time with planting, grazing or harvesting operations. Biosolids must not be applied to growing soft fruit or vegetable crops nor used where crops are grown under permanent glass or plastic structures (US department of the Environment, 1989). The EC Directive (Council of the European Communities, 1986) requires a mandatory 3-week no grazing period for treated biosolids applied to grassland but prohibits the spreading of untreated biosolids on grassland unless injected. Treated biosolids can be applied to growing cereal crops without constraint but should not be applied to growing turf within 3 months of harvesting or to fruit trees within 10 months of harvesting. When treated biosolids are applied before planting such crops as cereals, grass, fodder, sugar beet, fruit trees, etc., no constraints apply but in the case of soft fruit and vegetables, the treated biosolids should not be applied within 10 months of crop harvesting. In general, untreated biosolids should only be cultivated or injected into the soil before planting crops but can be injected into growing grass or turf, with some constraints on minimum time to harvesting as already mentioned, Table 1.5.

Table1.5 Planting, harvesting and grazing constrains to be observed when using biosolids as fertilizers (the EU codes of practices for t he use of biosolids in agriculture)

Crops to which biosolids can be applied while growing	**Crops to which biosolids can be applied prior to sowing /setting**
Cereals Oil seed rape Grass[1] Forestry[2]	Cereals Oil seeds rape Grass Sugar beat Animal fodder[1] Forestry[2]

[1] No harvesting or grazing until at least 3 weeks after application
[2] Not to be applied to upland forestry

1.1.6 Environmental protection

During the planning process for biosolids application to land, care should always be taken to prevent any form of adverse environmental impact. Biosolids must not contain non-degradable materials, such as plastics, which would make land disposal unsightly. Movement of biosolids by tanker from sewage treatment plant to agricultural land can create traffic problems and give rise to noise and odor nuisance. Vehicles should be carefully selected for their local suitability and routes chosen so as to minimize inconvenience to the public. Access to fields should be selected after consultation with the highway authority and special care must be taken to prevent vehicles carrying mud onto the highway.

Odor control is the most important environmental dimension of biosolids application to land. Enclosed tankers should be used for transporting treated biosolids, which tends to be less odorous than raw biosolids. Discharge points for biosolids from tankers or irrigators should be as near to the ground as is practicable and the liquid biosolids trajectory should be kept low so as to minimize spray drift and visual impact. Untreated biosolids should be injected under the soil surface using special vehicles or tankers fitted with injection equipment.

Great care is needed to prevent biosolids running off onto roads or adjacent land, depending on topography, soil and weather conditions. On sloping land there is the risk of such runoff reaching watercourses and causing serious water pollution. Biosolids application rates must be adjusted accordingly and, under certain circumstances, spreading might have to be discontinued. In addition to the problem of surface runoff, pollution may arise from the percolation of liquid biosolids into land drains, particularly when injection techniques are used or liquid biosolids are applied to dry fissured soils. In highly sensitive water pollution areas, biosolids should be used only in accordance with the requirements of the pollution control authority as well as of good farming practice. Biosolids storage on farms can optimize the transport and application operations but every effort must be made to ensure that storage facilities are secure.

1.2 Study Objectives and Significance

In Palestine, the concern regarding the efficient utilization of wastewater treatment products is currently one of the most priorities at formal and public levels, although the sector of wastewater treatment still suffering from poor design and improper operation and maintenance of the treatment plants, where only low purification efficiency could be achieved, although there are a huge plans for establishment of efficient wastewater collection and treatment facilities in Palestine (EMWATER-Project, 2004).

Most of the proposed plants which are under the donors priorities are mainly concentrated in the bigger cities and urban areas (e.g. Jerusalem, Hebron, Ramallah, and Nablus). Additionally the focus of current planned projects in the wastewater sector is more on large scale treatment facilities (e.g. German funding for WWTP in Al-Bireh). The planned and newly erected urban sewage works were donor influenced and initiated. Table 1.6 lists the current status of existed and planned wastewater treatment plants in the West Bank.

The reuse of reclaimed wastewater in Palestine is a major priority confirmed in the Palestinian Water Policy adopted by the PWA and the Ministry of Agriculture. Agricultural use of treated effluents was initially intended in Jabaliah and Gaza City. However, implementation failed due to lack of funds and rejection by local farmers because there is no cultural acceptance. Reuse of treated effluent may become realistic only if effective treatment systems are installed that provide effluents that comply with irrigation standards. This seems not to be the case with any of the existing treatment plants in Palestine (EMWATER Project, 2004).

Regarding the prospects of biosolids agricultural utilization in Palestine, still the issue is not discussed sufficiently as the case of effluent reuse. Moreover, the concern of biosolids utilization and safe disposal is existing, as most of major planned treatment units will apply the treatment technologies where a significant quantities of stabilized biosolids will be produced (activated sludge and extended aeration technologies) see table 1.6. The expected emerging sludge production and disposal problems will push up the efforts toward more interventions and investments to deal with this potential environmental contaminant.

By looking to the prospective future opportunities of biosolids utilization in Palestine, we can imagine how this valuable resource of nutrient can contribute in improving land fertility and therefore provides an efficient alternative for some chemical and inefficient organic fertilizers currently used widely for production of various types of crops. For instance, fodder crops which are mainly grown under dry land farming can be significantly benefit from this nutrients reservoir as these crops are highly depend on soil fertility and nutrients uptake from soil. The utilization of produced biosolids from the secondary treatment process can significantly contribute in productivity improvement for areas grown with fodders.

This study aimed to investigate the potentiality for utilizing biosolids produced from the secondary treatment process in Al Bireh WWTP as soil amendment organic fertilizer, and to increase the productivity for fodder crops, particularly the Egyptian clover (*Trifolium alexandrium),* which is one of the common fodder crops grown in Palestine under rain fed farming system.

In this study, the degree of biosolids compliance to land application guidelines and restrictions was investigated and compared with biosolids quality standards in terms of heavy metals concentration limits and suitability for land application. The study has also addressed the potential heavy metals retaining capacity of biosolids through measurement of heavy metals mass balance by comparing the mass entering the secondary treatment basins (extended aeration ponds), and the mass coming out of the plant with discharged effluent. This has provided an estimations of potential mass from each investigated heavy metals retained and accumulated in biosolids.

This study has also tried to clarify the conception of any proposed guidelines which could be developed to control biosolids land application practices in Palestine. By default, biosolids application are restricted on fodder crops as we have supposed that similar restrictions will be applied in utilizing biosolids on crops dedicated for human consumption.

Since the dewatering machines in AWWTP were not operational during the period of the study, biosolids samples were collected from the outlet of sludge thicker, directly before final disposal.

Table 1.6: Wastewater treatment plants (WWTP) in the West Bank -status and information (Bir Zeit University, EMWATER-Project, 2004)

Name of T.P	**Status of T.P**	**No. of population served by T.P * 1000 (year)**	**Capacity of T.P (mcm/year)**	**Funding Agency**	**Estimated cost for construction (million US$)**	**Technology**
Nablus East	Planning phase	240(2021)	9.2	Germany KfW	25	Extended Aeration
Nablus West	Approved	225(2021)	9.0	Germany KfW	25	Extended Aeration
Salfit	Detailed study	24(2025)	2.3	Germany KfW	13	Extended Aeration
Jenin*	Rehabilitation is needed	13.5(1997)	0.5	Israel		Waste stabilization ponds
Al-Bireh	Constructed	40(2000)	1.1	Germany KfW	7	Oxidation Ditch
Tulkarem**	No study yet	223(2030)	7.5	Germany KfW	50	Extended Aeration Process
Abu-Dees	Feasibility study	26(2020)	1	Norway		Oxidation Ditch
Tafuh	Feasibility study	16	0.5	UNDP		Anaerobic Rock Filter
Halhul	Preliminary design	42(2020)	1.0	Not funded	5.5	Aerated Pond System
Birzeit area	Preliminary Study	28(1994)	1.2	Not funded	4.5	Imhoff tank and trickling Filter
Hebron	Planning stage	695(2020)	25.0	USA	45	Activated Sludge
Jericho	Preliminary Study	26 (2000)	1.2	Not funded		
Biddya	Preliminary Study	24 (2000)	1.1	Not funded	10.0	
Ramallah***	Feasibility Study	40 (North)	1.5	Not funded	7.0	Extended Aeration
		40 (South)	1.5		7.0	
Al-Ram	Preliminary Study	86.5(2000)	3.3	Germany KfW	11.0	Aerobic sludge Stabilization+ Activated Sludge
Total		**1789**	**66.3**		**210**	

*Old and non-functioning sewage treatment plant exists. **Currently rehabilitation of the sewage treatment plant takes place. *** Currently rehabilitation of the old sewage treatment plant takes place as a partial solution.

1.3 Study area

1.3.1 Al-Bireh Wastewater treatment plant – treatment performance and operational status

Al Bireh wastewater treatment plant (Photo 1.1), was constructed to serve the population of Al-Bireh town (14 Km north to Jerusalem), and it is operated currently as the only treatment plant so far that is well functioning. The sewage treatment plants, entailing oxidation ditches and sludge processing units are working effectively. It was planned to utilize the treated effluent in agricultural purposes.

Photo 1.1: Al-Bireh Wastewater treatment plant

The wastewater treatment plant is successfully operating since August 2000. The WWTP has been designed for a capacity of 50,000 population equivalents and is extendable to a capacity of 100,000 population equivalents. The maximum daily dry weather flow is 5,750 m^3 /day and the peak hourly flow is 480 m^3/ hour at dry weather and 720 m^3/ hour during rainy weather conditions.

1.3.2 Biosolids production and disposal

1.3.2.1. Production

Biosolids production in Al-Bireh Wastewater treatment plant is mainly from pumping of excess sludge which is separated from the treated effluent in the secondary settling tank.

Usually, the quantity of pumped sludge is highly depending on daily estimations of sludge overload in the aeration tank and the need for the sludge during the wet weather diluted flow. Therefore, the sludge disposal from the thickener is varied mainly with the season. It is mainly disposed in large quantities in summer season, while the disposed quantities reduced at winter time especially during intensive rain fall period and high dilution of sludge in the aeration bonds due to the run off overflow.

The total storage capacity of the settling tank is around 361 m^3 (Photo 1.2) , and the average retention time of sludge in the thickener is around 3.5 days , which means that the tank is disposed twice a week in average. An average of 500 m^3 of liquid biosolids are disposed weekly at normal conditions, and this quantity is pumped to dewatering machines (Photo 1.3) at the time where these machines were functional, the average produced dewatered biosolids (solids content 16-22%) was around 80 m^3 weekly.

Based on these data, the annual production of biosolids has been estimated by 21000 m^3 of liquid biosolids and that quantity is equivalent to 3500 m^3 dewatered biosolids, or around 550 m^3 of dried Biosolids. The production of Biosolids in winter period (November till March) has been estimated by 50% of the quantity produced at summer period since the thickener tank is disposed once a week instead of twice a week in summer.

Photo 1.2: Sludge Thickener tank at Al Bireh WWTP

Photo 1.3: Dewatering machines at Al Bireh WWTP

1.3.2.2. Biosolids disposal

Disposal of liquid biosolids is carried out by pumping the biosolids directly to the adjacent areas, and mixed with effluent for long distance, causing a severe contamination to the surrounding areas (Photos 1.4, 1.5). Biosolids are contaminating the effluent to a distance very far from the plant location since both biosolids and effluent are mixed and flowed down.

Photos 1.4 and 1.5: Disposed Biosolids from AWWTP contaminating the surrounding areas

CHAPTER 2

LITERATURE REVIEW

2.1 Definition

Biosolids (also referred as Sewage sludge), is a complex mixture that can contain pollutants from household, commercial and industrial wastewater, organic and inorganic contaminants in addition to pathogens (Bacteria and Viruses) are often existed in biosolids that emerged from the process of wastewater treatment (US National Academy of science, 2002).

Method of biosolids disposal should be acceptable in terms of human and environmental safety, social acceptance and the cost, because of these restrictions, the appropriate biosolids disposal method in certain country is highly dependent on the economical situation and the local culture and traditions in addition to the specific topography and land availability (EPA, 1998).

Many studies and researches have been conducted worldwide to address the possibility and applicability of biosolids utilization in agriculture and the potential phytotoxicity impact. In this sense, biosolids can be perceived either as a waste or as a resource.

2.2 Biosolids as a valuable source of nutrients

Along with the reuse of the valuable resources resulting from wastewater treatment process, the appropriate use of nutrients found in biosolids is an interesting objective of wastewater reuse systems. The benefit of biosolids reuse onto agricultural land application include providing essential nutrients for crop needs and organic matter for improving soil tilt, water holding capacity, soil aeration , and an energy for earthworms and beneficial microorganisms (Evanylo, 1999).

Applications of biosolids improve the physical and chemical properties of soil and fertility, and the most beneficial effects of biosolids is through increasing the organic content of treated soils, (Connel et al., 1993). Biosolids also increased biological activity and enrichment with nitrogen, phosphorus and micronutrients (Brofas et al. 2000). Generally, digested or secondary biosolids contain higher nutrient content than raw or primary biosolids because much of the volatile organic matter has been given off as CH_4 or CO_2 during the digestion process (Hue. 2002).

Stehouwer. (1999) found in his study, that biosolids can improve soil fertility through the addition of organic matter and other plant nutrients such as sulphur, magnesium and sodium. Moreover, addition of biosolids increased the topsoil water-infiltration rates, plant-available water supply on a light sandy soil, soil porosity and bearing strength. There were also increases in the level of plant-available sulphur, magnesium, copper and boron. The same study has also s shoed the effect of digested biosolids applications on increasing the concentrations of major nutrients in grass.

According to Furrer et al. (1984), good correlations existed between the percentage of phosphorus utilization by plants and the phosphorus that can be extracted from biosolids. Authors concluded also that sludge is an effective source of phosphorus, although the actual quantity available is affected by the physicochemical characteristics of the soil, sludge characteristics, time and method of sludge application and the type of crop. However, the U.S. Environmental Protection Agency (1983) suggested that only 50% of the total phosphorus in biosolids is available in the first year.

Concerning effects of biosolids on plant growth and nutrient content, Koenig et al. (1998) reported that the application and incorporation of biosolids prior to the establishment of alfalfa (or alfalfa with an oat nurse crop), produced yields similar to those obtained with inorganic fertilizer. Moreover, researchers also found that biosolids application to grass hay resulted in yield that was intermediate between nitrogen fertilizer applied at 167 kg/ha and an untreated control. A potential added benefit of biosolids is an increase in the nutrient content of plant tissue. In grass hay, biosolids produced significantly higher concentrations of calcium, magnesium, phosphorus, iron, copper, manganese, and zinc than ammonium nitrate fertilizer. Moreover, the research has also showed that biosolids application to grass hay did not cause any increase in lead, cadmium, chromium, cobalt, or nickel.

Furthermore, Togay et al. (2008) found that the grain yield of dry beans (*Phaseolus vulgaris L*) increased significantly by applications of biosolids, and stated that data alkaline fine textured soils, which are suitable for dry bean production in Turkey, are deficient in nutrients for grain production, and that the applications of biosolids increased grain yields and yield components. The effects of different doses of biosolids applications on grain yield in dry bean were found by the researchers to be statistically significant.

2.3 Potential negative impacts

Biosolids are often regarded as major sources of potential metal pollutants despite the relatively small quantities of the residuals land-applied. The pollutants such as heavy metals are transferable and are not biodegradable, and at some levels, they become toxic and tend to accumulate along the food chain, where man is the last link (Dudka and Miller, 1999). In order to minimize the prospective health risks of biosolids during land application, many studies have been performed using various methods to study the chemical fraction and emendation of heavy metal in sewage.

The natural background concentration of metals in the soil is normally less available for crop uptake and hence less hazardous than metals introduced through biosolids applications (Scheltinga, 1987). Research carried out in the U.K. (Carlton, 1987) has shown that the amounts of Cd, Ni, Cu, Zn and Pb applied in liquid biosolids at three experimental sites could be accounted for by soil profile analyses five years after biosolids application, with the exception of Cu and Zn applied to a calcareous loam soil. These field experiments also determined the extent of transfer of metals from biosolids treated soil into the leaves, and edible parts of six crops of major importance to UK agriculture, and the effect of metals on yields of these crops.

Hue. (2002) has mentioned that two important factors that should be considered of when working with heavy metals in biosolids and in soils. First one is that the bio-availability of metals in biosolids is much lower than that of a pure metal salt, say biosolids -contained Cd vs. $CdCl_2$ or $CdSO_4$. The reason is that most metals in biosolids are in solid forms with very low solubility. They are either precipitated by carbonate and/or sulfide, complexed by organic matter, or sorbed by Fe, and Mn oxides.

The applications of biosolids affected crop yields in some cases. In 60% of the cases studied crop yields were not significantly affected, but in 26% of the cases biosolids application increased significantly crop yields. On the other hand, reductions from 6 - 10%, in wheat grain yield grown on clay and calcareous loamy soils treated with liquid biosolids were recorded. This yield reduction was not thought to be due to metals, but related to lodging of the crop as a result of excessive nitrogen in the soil (Koenig et al, 1998).

McBride et al. (2003) biosolids application to soil increased significantly Cd, Ni, Cu and Zn concentrations in the edible portion of most of the crops grown, and In most cases there was no significant increase of Pb in crop tissue in relation to Pb in the soil from biosolids 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 biosolids cake compared with liquid biosolids, the extent being dependent on the crop. Even though, Ni, Cu and Zn concentrations in the soils treated with high rates of liquid and bed-dried biosolids were close to the maximum levels set out in the EC directive. No phytotoxic effects of metals were evident in most cases.

Gardiner et al. (1995) reported that the concentrations of Cd and Zn in alfalfa increased following the addition of biosolids, particularly during periods of slower alfalfa growth. Even though some metal concentrations decreased by as much as 50% during rapid growth, the total metal extracted per pot often more than doubled. Cd and Zn uptake was about 40-50% higher from the two slightly acidic soils than from the two calcareous soils.

Additions of biosolids to soils have increased heavy metals in animals (Anthony and Kozlowski, 1982, Pietz et al, 1984, Bray et al, 1985). Since heavy metals are characterized to be bio-accumulated and biomagnified, acceptable non hazardous threshold levels in soils are hard to define. In the United States, standards of land application of biosolids have been established, based on the cumulative addition of various heavy metals (USEPA, 1989). The European Community standards are based on maximum allowable concentrations of metals in the soil and on soil pH (Wild, 1993). However, Sims and Pierzynski (2000) indicated that heavy metals concentrations in some manure equal or exceed those in modern biosolids.

The permissible concentration levels of toxic metals in crops or acceptable levels added to soil have been debated but not convincingly established. Some guidelines have been suggested for approximate tolerance levels in plant tissues used as animal feeds. The United States National Research Council (1980) suggested maximum levels of Cd, Cu, Ni and Zn in feed, separately for cattle, sheep, swine and chicken. The maximum tolerable levels for sheep are 0.5 mg kg for Cd, 25 for Cu, 50 for Ni, and 300 for Zn, (Chaney, 1983).

Logan et al. (1997) concluded that crop uptake of soil Cd would be less from soil treated with biosolids with low Cd compared to a high-Cd biosolids, even when actual Cd loadings were similar.

In this respect, it is worth to mention that the bio availability of metals in biosolids is much lower than that of a pure metal salt. Reasons for that is that most metals in biosolids are in solid forms with very low solubility. And that are either precipitated by carbonate and /or sulfide, complexed by organic matter, or sorbed by Fe and Mn oxides (Hue et al, 1998).

Furthermore, the study of Ian et al. (2008) indicated that the long-term land application of class B biosolids showed enhanced microbial activity and no adverse toxicity effects on the soil microbial community. Long-term land application also increased soil macronutrients including C, N, and, in particular, P. In fact, care should be taken to avoid contamination of surface waters with high phosphate soils

Based on aforementioned findings, it is clear that the consumption of plants containing high levels of heavy metals might pose a serious risk to human health (Turkdogan et al., 2003; Wang et al., 2003). Depending on the environmental conditions and the rate that heavy metals are added to the soils, these elements can be leached through the soil profile, and consequently contaminate groundwater. Antoniadis & Alloway. (2003) studied soils that received heavy loads of biosolids and pointed out that the movement of heavy metals was significant down to the 0.8 m soil depth, suggesting the risks of applying this residue for a long period. Since heavy metals do not break down, they might affect the biosphere for a long time. Wang et al. (2003) investigated heavy metal contamination in soils and plants at polluted sites in China, and reported the problems associated to the consumption of rice grown in paddy soils contaminated with Cd, Cr or Zn, since around 25% of the total metals was concentrated in the grain.

2.4 Regulatory Overview

Over the past 30 years, there has been an intense and concerted effort of scientific research worldwide for better understanding of the fate of potentially toxic and pathogenic constituents in biosolids when applied to agricultural soils. The surge of technical information regarding agricultural application of biosolids led to the development of pollutant loading guidelines in many countries. In addition to that, biosolids guidelines identify sensitive areas in which application is not permitted. Buffer zones are placed around these areas to protect land uses such as drinking water catchments, national parks, residential areas, occupied dwellings, and groundwater bores and surface (Rawlinson, 1997).

In addition to that, Risk assessment rules and procedures that are related to land application of biosolids were established in many countries. in fact the process was developed in Parallel to the growing trends for safe management and disposal of increasing quantities of biosolids that originated from wastewater treatment process.

The permissible concentration levels of toxic metals in crops or acceptable levels added to soil have been debated but not convincingly established , Some guide-lines have been suggested for approximate tolerance levels in plant tissues used as animal feeds (Gardiner et al., 1995).

2.4.1 USA-EPA regulations

In 1993, the U.S. Environmental Protection Agency (EPA) promulgated 40 CFR Part 503 to address the Clean Water Act’s (CWA) which requirement was developed to regulate the use or disposal of biosolids. The pollutant limits and management practices in Part 503 protect human health and the environment, as required by the CWA. Another key component of the rule is the operational standard that requires reduction of pathogens (i.e., disease-causing organisms) and of vector attraction (e.g., insects, rodents), using specified operational processes (e.g., treatment), microbiological monitoring, and physical barriers (e.g., injection or incorporation) for biosolids to achieve this reduction.

2.4.2 Israeli regulations

The trend in Israel is to gradually convert outdated extensive wastewater treatment systems to intensive plants. However, wastewater treatment plants, which use the activated sludge method, generate large quantities of biosolids, at a scope of hundreds of tons of dry matter per day. Biosolids quantities have already exceeded 110,000 tons per year (dry weight), of which 58,000 dry tons/year are produced by the Dan Region Wastewater Reclamation Project. This untreated activated sludge is discharged into the Mediterranean Sea via a 5-km long marine outfall, at a water depth of 38 meters. However, by 2008, when the permit for discharge to the sea will expire, a land-based solution to produced biosolids will have to be implemented. With the exception of biosolids produced by the Dan Region Wastewater Reclamation Project, most of the rest of biosolids currently produced in Israel is beneficially utilized in agriculture for non-edible crops.

The Ministry of the Environment regards biosolids as a valuable resource for fertilization and soil improvement. Therefore, the Ministry of the Environment, in cooperation with the Ministries of Health and Agriculture, has formulated guidelines and draft regulations which require wastewater treatment plants to stabilize and treat biosolids they generate as a condition for agricultural use or soil improvement. The draft regulations establish maximum permitted levels for heavy metal and pathogen concentrations in biosolids designated for agricultural use, defines specific uses for class A and B biosolids, and sets limitations on areas of biosolids use.

2.4.3 Directives of the European Economic Commission (No. 86/278/EEC)

The application of biosolids to land in member countries of the European Economic Commission (EEC) is governed by Council Directive No. 86/278/EEC. This Directive prohibits biosolids from sewage treatment plants from being used in agriculture unless specific requirements are fulfilled. These specific requirements include dry matter%, Organic matter%, % dry solids in addition to concentration levels of Nitrogen (total and ammonical), Phosphorus, Copper, Nickel, Zinc, Cadmium, Lead, Mercury and Chromium in mg/kg dry biosolids.

To these parameters the UK Department of the Environment (1989) has added molybdenum, selenium, arsenic and fluoride in the recent 'Code of Practice for Agricultural Use of Biosolids'. Biosolids must be analyzed for the Directive parameters at least once every 6 months and every time significant changes occur in the quality of the sewage treated. The frequency of analysis for the additional four parameters may be reduced to one in five years provided that their concentrations in biosolids are consistently not greater than the following reference concentrations: Mb 3mg/kg dry solids, Se 2mg/kg dry solids, As 2mg/kg dry solids and Fl 200mg/kg dry solids.

2.4.4 Regulations of Industrial wastewater discharge from Al Bireh industrial zone

By referring to the study which was conducted in 1999 the GTZ, as a preliminary assessment of industrial wastewater quantity and quality which produced by the various industrial activities in Al Bireh town and enter the combined sewerage system to be discharged finally to the treatment plant, we will find that Al-Bireh municipality has issued up to that date 859 licenses for businesses that need licenses of which 171 of the licensed businesses handle materials that may harm the wastewater treatment plant. Moreover, it is estimated that additional 15% do businesses without license. This study has focused on performing an assessment to the potential impact of the industrial wastewater discharge on the treatment performance of the newly constructed WWTP in Al-Bireh.

The study has classified the discharged effluents of the existed industries to:

- **Low polluting effluents** which produced by laboratories, film processing, Gas filling stations, Pharmacies, detergents producers.
- **Medium producing effluent** which produced sweets shops, dry cleaning companies, restaurants, hotels, car washing companies and hospitals.
- **Potentially heavily polluting effluents** which produced by stone cutting factories, suction trucks, car maintenance, slaughter house, Diary, Palestine Aluminum Company, electrochemical metalizing establishment and Pharmaceutical factories).

In this respect, the main businesses under consideration were the Aluminum company effluent and the electrochemical metalizing company both in Al Bireh Industrial Zone.

The sewerage by- low of Al-Bireh municipality (for the year 2000) has specified an obligatory guidelines for industrial effluent quality. By this law, pollutants concentration in this effluent shall not exceed the identified limits, the limits of maximum allowed heavy metals concentrations in industrial effluent are shown in table 2.1.

Table 2.1: The maximum concentration of heavy metals in industrial effluent to be discharged in the public sewerage system (the sewerage by law of Al Bireh municipality, 2000)

Metal	Maximum concentration mg/l for discharge greater than 50 m^3/day	Maximum concentration mg/l for discharge between 15-50 m^3 /day	Maximum concentration mg/l for discharge less than 15 m^3/day
Zn	5.00	10.00	15.00
B	3.00	4.00	5.00
Cr	0.50	2.00	5.00
Cu	1.00	2.00	4.50
Cd	0.10	0.50	1.00
Al	25.00	25.00	25.00
Hg	0.010	0.10	0.50
Mn	1.00	2.50	5.00
Ni	1.00	2.50	4.00
Pb	0.25	0.40	0.60

Tables 2.2 and 2.3 below show the analysis results for generated wastewater of 2 main factories which are considered the main potential sources of heavy metals entering the sewerage system of Al Bireh, the effluent analysis were performed during the GTZ study of industrial discharge quality to show the degree of compliance with the permissible limits identified in sewerage by law of Al Bireh municipality.

Table 2.2: Industrial effluent analysis for Palestine Aluminum Company before and after the onsite treatment of discharge

Metal	Concentration before primary onsite treatment in mg/l	Concentration after primary onsite treatment in mg/l
Al	5.67	0.656
Cd	nd	nd
Cr	26.30	0.256
Cu	nd	nd
Ni	0.589	nd
Pb	nd	nd
Zn	0.293	0.114

Table 2.3: Industrial effluent analysis for electrochemical metalizing company

Metal	Concentration in mg/l
Al	1.69
Cd	0.055
Cr	2.96
Cu	0.397
Ni	0.297
Pb	0.082

2.5 Al-Bireh biosolids Composting and Reuse of Reclaimed Wastewater demonstration

Within the framework of the USAID project for the Hebron Wastewater Treatment Plant, a demonstration reuse project has been conducted at the site of Al-Bireh wastewater treatment plant. Reuse of both biosolids and treated wastewater has been practiced in partnership with the Palestinian Water Authority, the Municipality Al-Bireh and the CH2MHill West Bank Water Resources Programme. It was intended as a demonstration project for the Palestinian institutions who will be involved in future in wastewater treatment and residuals management projects.

The objectives of the composting demonstration project were to demonstrate the role of reuse and the potential agricultural value of biosolids, to demonstrate a sustainable alternative for land filling of biosolids and to demonstrate the management of a biosolids composting system. The main activity of the demonstration project was the composting of biosolids generated at the Al-Bireh Wastewater Treatment Plant (WWTP) in a windrow system and subsequent reuse in agriculture. The target was to generate compost that complies with the strictest standards under Israeli and USEPA regulations for unrestricted land application of the composted biosolids.

The composting process has occurred in an optimal environment of porosity and moisture content and in the presence of a carbon source. In this process temperature increased to 55°C, pathogens are eliminated and organic matter and odors decrease. The project established this environment by shredding of a carbon source and bulking agent (cardboard), mixing and testing compost feeds tocks of biosolids and shredded bulking agent, stacking the composting windrows, monitoring temperature, pH and moisture content and re-stacking and watering the composting piles.

The main activity of the project is the construction and management of 6 dunums reclaimed water drip irrigation system at the site of the Al-Bireh Wastewater Treatment Plant (WWTP). The high quality reclaimed water of the WWTP is used to irrigate a range of common Palestinian crops: orchard and ornamental trees, grape stocks, processed vegetable and flowers and ornamental shrubs. Very high quality reclaimed water is used to irrigate a 600 m^2 greenhouse with cultivation of cooked vegetables (not for commercial purposes) and commercial nursery crops (Nursery producing 23,000 seedlings/year). The greenhouse is operated under a public-private partnership with a Palestinian nursery.

CHAPTER 3

RESEARCH DESIGN AND APPLIED METHODOLOGIES

3.1 Introduction

This research consisted of 2 main parts. The first part included the lab work, and the second part the field experiment of biosolids application to soil. Both parts were applied in a consequent way as the first part aimed to assess the suitability of the produced biosolids to be used as organic soil fertilizer and its impact on crop growth and development.

Biosolids characterization and determination of its quality were performed through collecting of biosolids samples from AWWTP sludge thickener, analysing these samples for heavy metals concentration, and interpreting the results to determine the suitability of biosolids to be applied on agricultural land.

The impact of biosolids application on the growth and production of Egyptian clover has been investigated through the measurements of growth and productivity indicatores. The potential negative phytotoxicity impacts on cultivated crops, as well as the positive impact on growth and production indicators has been assessed and monitored over the study period. Moreover, the mass balance of heavy metals entering the treatment plant of Al Bireh has been measured to estimate the quantities of each heavy metals potentially retained in the disposed biosolids.

The concentrations of heavy metals in both influent and effluent samples have been also determined for collected samples at specific time intervals. The purpose of these analyses was to have clear indicators about types of heavy metals entering the activated sludge basins through the coming flow of raw wastewater. Further, it was also important to estimate quantities from different investigated heavy metals which could be retained in biosolids by comparing the concentrations of these heavy metals in the treated flow getting out of the treatment plant (effluent), mainly from the secondary settling tank.

The first part of this study has aimed at performing an assessment if biosolids quality and its applicability for land application in terms of concentration limits of seven investigated heavy metals (Zn, Cu, Cr, Ni, Pb, Cd, As), in addition to Boron (B), which are commonly known to pollute wastewater and to have a considered phytotoxicity impacts on crops grown in soils amended with biosolids (see table 1.2).

The selection of these metals was based on the finding of the study “preparation of the industrial wastewater Cadastra for Al Bireh which has been implemented by the GTZ in December 1999. This study defined the main producers of industrial discharge from Al Bireh Industrial zone with measured concentrations of organic and inorganic pollutants including heavy metals.

3.2 Heavy metals determination and mass balance assessment for biosolids of AWWTP

The experiment methodology included four main steps:

I. **Samples collection**: This include the collection of requested samples (biosolids and wastewater) from the source (Al Bireh WWTP), applying a recommended sampling and preservation techniques. Collected samples of biosolids and wastewater from influent and effluent have been handled to prepare them to perform the planned analysis and characterization. Preparation included samples drying, digestion, dilution and preservation. Collected samples were subjected to initial analysis to determine the basic characteristics (pH, TDS, TSS ...etc), whereas the finally prepared samples have been used to determine the heavy metals concentrations.

II. **Lab analysis-primary and spectrophotometric analysis of heavy metals concentrations:**

Samples analysis has performed in two steps:

- **Primary analysis for samples characterization**: These analyses were done directly after samples collection to identify the main characteristics of biosolids and wastewater.
- **Samples analysis by spectrophotometer:** samples were analyzed by Inductively Coupled Plasma – Atomic Emission Spectrophotometer ICP-AES, to assess the concentrations of Pb, Zn, Cu, Ni, Cr, Cd, As, and B.

III. **Mass balance calculation and biosolids quality determination:** Analysis results for heavy metals concentration for wastewater influent and effluent of Al Bireh WWTP has been performed. These analyses provided partial information's about potential mass of each heavy metal which is retained in biosolids. The assessment of mass balance formula for each heavy metal was done by converting the concentration to mass in both influent and influent flows. By default, the difference between coming in and coming out masses represents the mass retained and incorporated with biosolids.

IV. **Biosolids application to soil and utilization as organic fertilizer:** Biosolids (sewage sludge) were dried and applied to the prepared soil plots in different application rates. The soil was seeded Egyptian clover seeds. Heavy metal toxicity symptoms and plant growth rate indicators were used to monitor the impact of biosolids application.

3.2.1 Sampling procedure

A particular concern in sampling process was to collect samples that are representative to entire contents. Accordingly, three types of samples were collected in each sampling round. Samples were collected from the raw WW Influent, treated WW effluent in addition to the stabilized biosolids samples from the thickener tank. The followed procedure of sampling was according to the "standard methods for the Examination of Water and Wastewater 20th edition, 1998".

3.2.1.1 Biosolids sampling

A grab biosolids samples were taken during two periods. The first period was from November 2006 through February 2007. The second sampling period was from April through June 2007. A total of 10 samples has been collected and analyzed from the sludge thickener, including biosolids which has been dried and applied in the second part of this experiment. It was proposed to collect biosolids samples from the final sludge disposal containers where biosolids are usually disposed after dewatering, but because the dewatering machines were defect at the study period, the other option was to take samples from the final outlet of the sludge line, the outlet valve which is used to discharge the collected biosolids in the sludge thickening tank.

A grab samples were collected in a frequency of 1 sample each 12-16 days and the time of sampling was between 10:00 to 11:00 AM. The time of sampling where scheduled to be done at the time where the thickener is nearly full, and before biosolids disposal.

Sampling procedure from the sludge thickener disposal valve has been applied as follows:

- The valve opened carefully to repel the accumulated Gases (mainly H_2S and CH_4) in the pipes.
- After flow started to come out, biosolids were left to discharge from the valve for 5 minutes before starting sample collection.

- Samples were taken during 10 minutes in a sporadic manner, by which a part of the sample was collected each 1 minute during the valve operation, and the collected samples were homogenized by continuous mixing.
- A 1.5 liter poly ethylene bottles were used to collect biosolids samples. The bottles were rinsed with diluted HNO3 solution and washed with distilled water before usage. In addition to these measures, the first quantity of collected biosolids was used to wash the bottles before the final sample collection.
- Collected samples were sent directly to the laboratory to start the sample preparation and to perform the primary analysis (Photos 3.1, 3.2, 3.3).

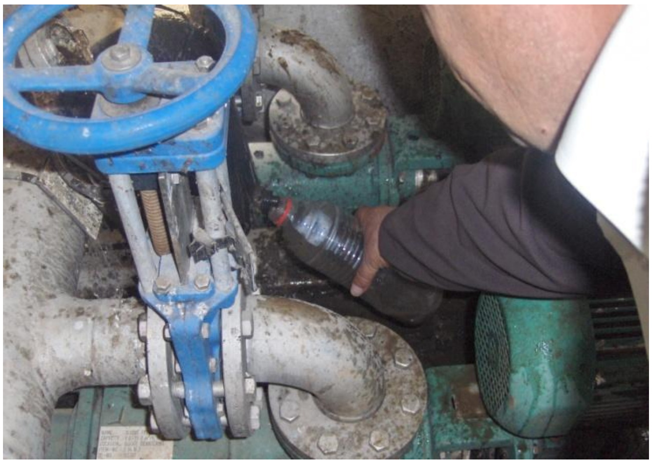

Photo 3.1: Sludge sample collection

Photo 3.2: Outlet valve of sludge thickener

Photo 3.3: Sludge sample ready to be sent to laboratory

3.2.1.2 Wastewater sampling

The followed procedure for wastewater sampling was the same as biosolids. For each sampling cycle, two samples were collected, the sample from the raw wastewater coming in to the plant (influent sample), in addition to the sample from the treated wastewater coming out of the treatment plant (effluent sample).

Sampling points and frequency

Samples from raw wastewater Influent were collected from the end of the grit removal channel and before wastewater discharge to the secondary treatment unit (extended aeration bonds). The aim was to investigate the concentrations of heavy metals which entered the biological treatment phase in aeration bonds, whereas the effluent samples were collected from the secondary settling tank before final discharge of treated wastewater. A total of eight samples were taken from each type with an average of 15 days period between samples.

- **Sampling tools**

Samples were collected using clean polyethylene bottles. A 1 liter samples were collected from each type in a sporadic way. Samples were collected during 15 minutes period of continuous flow. Samples were sent to the laboratory within 1 hour of sampling.

3.2.2 Primary analysis and digestion of samples

3.2.2.1 Biosolids characterization

Raw biosolids samples were initially characterized through performing primary analysis. Biosolids characterization has mainly focused on the physical and some basic chemical characteristics which may influence the soil properties.

Values of EC, pH, TDS, TVS have strong impact on soil quality and plant utilization of soil minerals. The determination of solid content is also of great importance to estimate the maximum quantities which can be applied in terms of dry matter content.

Primary analyses which have been performed to identify the basic characteristics of sampled biosolids were electrical conductivity (EC value), pH, TS, TSS, TDS, TFS and TVS.

I. **pH and Electrical conductivity** were conducted using pH and EC meters

II. Solids content

TS are the total of all solids in a water sample. They include the total suspended solids, total dissolved solids, and volatile suspended solids. The analytical reference for solids calculation is Reference: Standard Methods; 2540 A, 2540 B, 2540 D, 2540 E, 2540 G.
Total solids content has been determined in order to calculate the actual quantities from solid biosolids which will be added to the soil if the liquid biosolids applied directly to soil. it is also important to determine the organic components and other dissolved and none dissolved minerals in the biosolids. Additionally, the heavy metals concentration will be referred to the dry weight.

The solids content in liquid biosolids gave also indicators about the thickening efficiency. This important characteristic is the initial step in determining other physical parameters to investigate the main physical characteristics of biosolids.

Total solids (TS)

Total solids content has measured by the conventional drying procedure. The following steps were followed to determine TS content.

- 50 ml from fresh biosolids were introduced to pre-weighted sterilized cups (crucibles) and incubated in the Laboratory furnace for 24 h at 105 °C.
- The sample were dehydrated to measure the total solid content in g/l
- The mass of dried biosolids was measured by comparing the weight of empty crucibles before and after drying.
- Three replicates were done for each sample.

Total solids were measured according to the following formula:

$$\mathbf{S = W_d / L_V * 1000\ ml}$$

S: solid content in g/l

W_d: sample dry weight in grams

L_V: sample original volume in milliliters

Photo 3.4: Incubating Biosolids samples in furnace at 105 °C

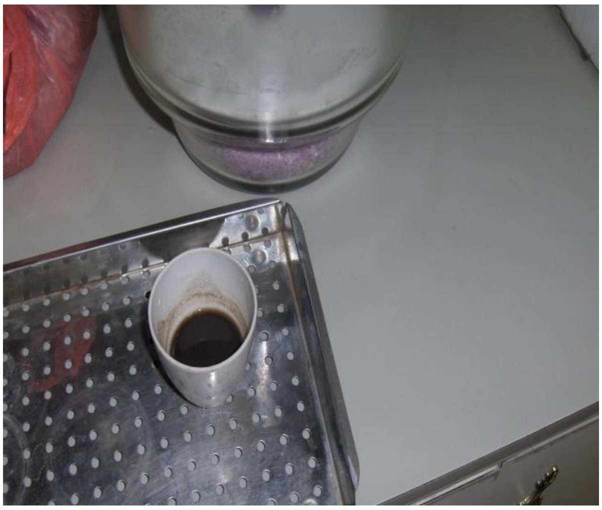

Photo 3.5: Biosolids sample in crucible for TS measurement

Total suspended and total dissolved solids (TSS &TDS determination)

Samples were filtered through a glass fiber filter. The filters were dried and weighed to determine the amount of total suspended solids in mg/l of sample.

For the total suspended solids (TSS), and total dissolved solids (TDS) determination, the following procedure was applied:

1. Biosolids sample where homogenized by shaking and immediately a volume of 50 ml of biosolids samples were poured in a sterilized crucible.
2. Biosolids sample where filtered using air suction system to extract the liquid proportion.
3. The pre-weighted filter paper with retaining solids was fixed inside a metallic tube with known weight (photo 3.8), the tube with the attached filter paper with attached biosolids were dried in the over for 24 hours at 105°C
4. The weight of tube was taken after drying and the suspended solids weight was calculated according to the formula:

$$\mathbf{TSS\ (g/l) = (W_f - W_i) * 1000 / V}$$

TSS: total suspended solids content in the sample in g/l

W_f: final weight of tube and contents after drying (g)

W_i: initial weight of tube and filter paper before drying (g)

V: sample volume in ml

Photo 3.6: Suspended solids determination through suction filtration of sludge sample

Photo 3.7: The suction setup ready to start sample filtration

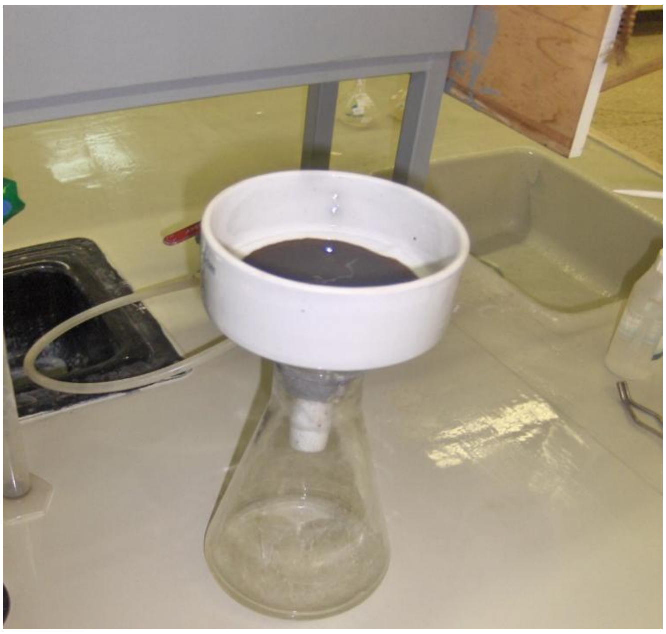

Photo 3.8: Filter paper with attached solids fixed inside the metallic tube

Simply, the TDS calculated as the difference in weight between Total solids and Total suspended solids. The simple direct formula is:

TDS = TS – TVS

TS: total solids in the sample (g)

TDS: the measured total dissolved solids (g)

Total volatile Suspended solids (TVSS)

Volatile solids are those solids lost on by vitalization, when sample is burned at 550°C. They are useful to the treatment plant operator, because they give a rough approximation of the amount of organic matter present in the solid fraction of wastewater, activated sludge, and industrial wastes.

After calculating the total volatile solids by incubating the sample prepared in the previous section, the measured dried sample has been burned inside the Laboratory furnace at 550°C. Therefore the volatile (organic) compounds will be volatized and the fixed mineral part will remain in the sample (Photo 3.9).

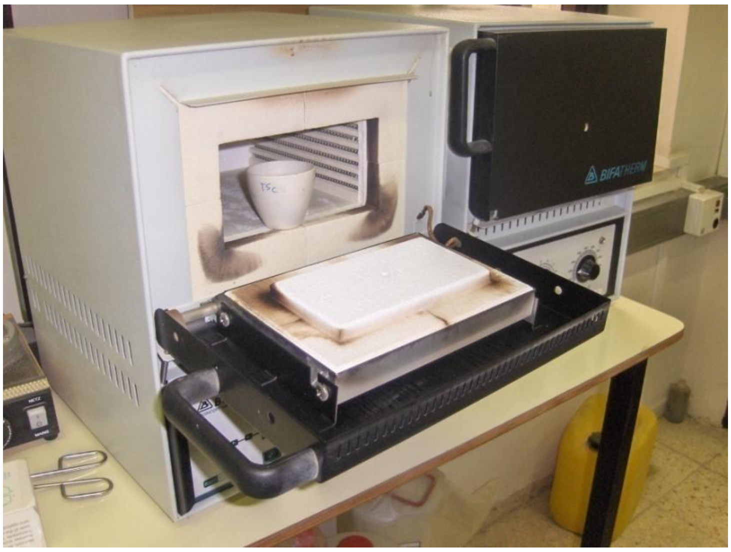

Photo 3.9: Sample volatilization for TVSS measurement

The formula for calculating the total volatile solids is simple and direct. Three replicates had been processed during the TVS calculation and the average of these samples:

$$\textbf{TVS = TS (initial) – TS (final) * 1000 / V}$$

TVS: total volatile solids (g/l)

TS: initial weight of total solids (g)

TS: final weight of solids after burning sample at 550 °C (g)

V: the sample volume in ml

The total fixed solids in the sample were calculated as the difference between the TVS and the TVSS content.

3.2.2.2 Biosolids samples digestion

In order to be analyzed for heavy metals determination by atomic emission spectrometry. Chemical digestion was required for samples to get red from all organic solids particles.

Biosolids and wastewater samples were handled through the same digestion procedure, the followed digestion procedure according to the standard procedure for examination of water and wastewater published jointly by the American Public Health Association, American Water Works Association and the Water Environmental Federation in the USA (standard methods, 20th edition, 1998).

Usually, a preliminary treatment is required to present the metals in a sample to the analytical methodology in an appropriate form. The preliminary treatment represented by sample digestion with acidic reagent, samples containing particulates or organic materials generally require pretreatment before spectroscopic analysis. It was important to get colorless and transparent samples of turbidity < 1 NTU, no odor and single phase to be analyzed by atomic absorption/emission spectrometry.

Procedure for sample acidic digestion

Nitric acid (HNO_3) digests most samples adequately, although some samples may require addition of hydrochloric (HCl) for complete digestion. In this experiment, HNO_3 - HCl (1:3) solution was used.

Fresh wastewater samples were digested directly after sampling, whereas biosolids samples were digested after drying.

A. Wastewater samples (Influent and effluent)

- Samples were homogenized by shaking the bottles before sample pouring into special crucibles.
- Crucibles were introduced to the heating chamber for 30 minutes for sterilization.
- Aqua regia digestion solution was prepared by mixing HCl (32%) and HNO_3 (65%), at a ratio 3:1 (v/v; HCl: HNO3).

- 25 ml from each sample were used for digestion. Each sample was digested with 20 ml aqua regia solution for 40 minutes with continuous boiling on plate heater (photo 3.10).
- The digestion process was continued until the sample turned clear (disappearance of all particles and other solid Impurities in the sample).
- 3 replicates from each sample were prepared and digested. Samples were preserved in polyethylene sterilized bottles (pre-washed with HNO_3).
- Samples were then diluted by distilled water to the volume of 100 ml and incubated in the refrigerator (temperature below 5 °C, photo 3.11).

Photo 3.10: Biosolids sample digestion on a plate heater

Photo 3.11: Samples diluted and kept in refrigerator at below 5 ° C

B. Dried biosolids sample:

Biosolids samples were digested using similar procedure mentioned above. In brief, an accurate weight of 0.5 g of dried biosolids has been taken for acidic digestion. It was digested with heating for 40 minutes till the sample turned clear and transparent solution. Sample then cooled and preserved in PE bottles

Since the digested samples of extremely high acidity (pH was undetectable), which may impede significantly the analysis process, samples were diluted with distilled water to a volume of 100 ml to rise the pH to an acceptable limits.

3.2.3 Heavy metals determination by inductively coupled plasma spectrophotometer

Metals are analyzed usually using either Atomic Absorption Spectrometry (AAS), or Inductively Coupled Argon Plasma (ICAP). In biosolids application, it is important to realize that both of these analytical techniques are reliable tools and neither offers a significant technical advantage over the other (EPA sludge sampling and analysis guide). However, ICAP's capability to simultaneously analyze multiple elements is a tremendous advantage in terms of sample throughput and labor savings. In this research, the ICAP was used to determine the concentrations of heavy metals for all sample types (biosolids, influent and effluent).

Inductively Coupled Argon Plasma is a form of optical emission spectroscopy which uses argon plasma to excite ions and atoms. This process causes the ions and atoms to emit light which is measured as a signal. The signal response is proportional to concentration level, and each element emits a uniquely characteristic light. A linear relationship between concentration and signal response can be expected over 4-6 orders of magnitude, and detection limits are low, although not as low as AAS, and not strongly inhibited by matrix variation.

ICP analyses were performed by the ICP instrument in the laboratory of health and occupational safety center at Bir Zeit University (photo 3.12).

Photo 3.12: ICP-AES instrument used for heavy metals analysis

Samples were subjected to analysis by ICP-AES. The instrument were calibrated using a multi-standards solution and the standard method (analytical method 3125A Metals by ICP-AES) was followed (see table 3.1 for more specifications).

Table 3.1: Recommended wavelength (nm), for accurate detection limits of each analyzed metals using the ICP- AES analytical method (Standard methods, 20th edition)

Metal	Special wave length (nm)	IDL* in (µg/l)
B	249.773	5
Zn	213.856	2
Cu	324.754	6
Ni	231.604	15
Cr^{+3}	267.716	7
Cd	214.000	4
Pb	220.353	40
As	193.696	50

*Instrument detection limit

By looking to the instrument detection limit mentioned in table 3.1, we can realize the difficulty in measuring Lead and Arsenic by using the ICP-AES, since the detection limits for those elements are too high.

Concentration measurement in diluted wastewater samples

The concentration values which has been obtained by analyzing the diluted samples were used to measure the concentration in original sample according to the correction formulas:

$$\mathbf{Cf = C * D/V}$$

Cf: final concentration in the original sample in µg/l.

C: calculated concentration in diluted sample.

D/V: dilution factor where D is the final volume after dilution and V is the original volume of the digested sample.

In our case, the dilution factor was 4 (the original sample volume was 25 ml, and the final diluted volume was 100 ml). The concentrations values obtained through ICP-AES were measured in parts per billion (ppb).

Concentration measurement in biosolids sample

Obtained values were converted to mass/mass ratio in order to standardize the measurement in terms of heavy metals content in dried biosolids. The concentration of heavy metal in analyzed diluted sample was converted to mass according to the formula.

$$\mathbf{S = C * (100/1000)}$$

S: mass of heavy metal in the analyzed biosolids sample.

C: concentration of analyzed metal in the diluted sample (in µg /l).

Metal content in the original biosolids sample in µg/kg dry weight can be calculated according to the following equation

$$\mathbf{M = S * 1000/m}$$

M: mass of analyzed metal in dry biosolids sample in µg/kg dry weight

S: mass of the analyzed metal in diluted biosolids sample in µg (the concentration in µg /l * the volume of diluted sample in liters).

m: original mass of the diluted dried biosolids sample in grams.

3.2.4 Mass balance assessment

The mass balance (also called a material balance) is an application of conservation of mass to the analysis of physical systems. By accounting for material entering and leaving a system, mass flows can be identified, which might have been unknown, or difficult to measure without this technique. The exact conservation law used in the analysis of the system depends on the context of the problem, but all revolve around mass conservation, i.e. that matter cannot disappear or be created spontaneously.

Mathematically, the mass balance for Heavy metals can be measured by the following formula:

$$\mathbf{R_m = (C_I * F_I) - (C_o * F_o)}$$

R_m : retained mass (kg)

C_I : heavy metal concentration in the influent (mg/l)

F_I : daily wastewater influent in l /d

C_o : heavy metal concentration in the effluent (mg/l)

F_o: daily wastewater influent in l /d

In this study, the aim from applying the mass balance equation is to assess the estimated quantities of heavy metals which are potentially retained in biosolids, when precipitated or removed from influent during treatment.

By comparing the mass of heavy metals in the outflow (treated effluent) and the mass in the inflow (raw sewage), the estimated retained mass of each metal was estimated on daily basis, since the daily flow rate of raw sewage and outflow were obtained from the logs of AWWTP for the sampling days, and therefore a 10 results were recorded. Accordingly, the average of retained biosolids for each metal was estimated for the 10 measurements.

3.3 Assessment of biosolids application impacts on crop growth and productivity of Egyptian clover (*Trifolium alexandrium*)

The aim from this part was to assess the potential positive and negative impacts of biosolids application on plant growth, and heavy metals toxicity.

A suitable crops to use of biosolids are field crops, this include field corn for grain or silage, small grains (wheat, barley, oats, rye), and forages (grass, hay, pasture, silage). These crops have relatively high nitrogen requirements, show yield responses to nitrogen, and have maximum production at a soil pH of 6.0 - 6.5. Legumes (alfalfa, clovers, soybeans, birds foot trefoil), non-harvested cover crops, ornamental field nursery stock, and turfs are also suitable crops, but not as grass and monocot grain crops.

According to its assessed quality in terms of salinity values, pH, solids content and concentration limits of heavy metals, it was decided work with Egyptian clover.

3.3.1 Basic definitions:

- **Ceiling concentration limits**: the maximum allowable concentration of a pollutant in biosolids to be land applied. If the ceiling concentration limit for any regulated pollutants is exceeded, biosolids cannot be land applied.

- **Cumulative Pollutant Loading Rate:** the maximum amount of an inorganic pollutant that can be applied to an area of land.

By assuming that the Palestinian standard for reusing treated effluent in agriculture is also applicable in the case of disposed stabilized biosolids, it is not allowed to apply biosolids to edible crops. For this purpose, a non-edible fodder was selected to perform the study.

3.3.2 Applied methodology

3.3.2.1 Crop selection

To perform this study within the available limited time period, a fast growing annual crop was required with strong vegetative structure. Moreover, and due to the absence of local regulations that allow biosolids application to lands planted with human edible crops, vegetables, legumes and grain crops were excluded, the suitable crop were determined to be one of the annual rain fed fodder crops.

For this experiment, Egyptian clover that used as an animal feed, was selected to be the experimental crop. Many reasons have pushed toward selection of this variety where the main reasons are:

1. Egyptian clover is a common fodder crop in Palestine and it is cultivated as an annual winter crop. The productivity of this crop depends largely on the average annual rain fall during the cultivation season.
2. This crop is known with its tolerant of salinity and alkalinity in soil and irrigation water. It is recorder that *Trifolium alexandrium* was used in reclamation of "salty" land in Egypt (Munoz & Graves, 1988).

In Palestine, lands cultivated with Egyptian clover are usually supplied before planting with chemical fertilizers with additional organic fertilization (cow or chicken manure). After planting, farmers used to apply additional chemical fertilizers, mainly ammonium sulphate and urea.

3.3.2.2 Crop characteristics

Egyptian clover (*Trifolium alexandrium* L; Arabic: Berseem), is a common annual forage crop in the Middle East area. Berseem clover is an erect-growing annual legume with oblong, slightly hairy leaflets lacking a watermark. It has hollow stems and a short taproot. Flowers are yellowish white, self-sterile, and clustered in dense elliptical heads about 1 inch long. Each floret produces one roughly-spherical yellow seed (Graves et al., 1987). Berseem clover flowers are self sterile and are pollinated by honeybees (Knight, 1985).

Egyptian clover is grown in Palestine in rain fed areas located in the northern and middle parts of the West Bank where the average rainfall exceeds 400 mm /year. The crop could be harvested either as one mowed batch (after 90-100 days of planting), or could be mowed up to 3 times, that depends mainly on rainfall season intensity and distribution.

3.3.2.3 Biosolids preparation

The first process in biosolids preparation was drying. After that, the pre-application treatments (grinding and fining) and then mixing with soil of the experiment treatments site was conducted.

In order to facilitate biosolids transportation from the treatment plant, it was necessary to apply a physical drying procedure, where it could be possible to utilize the sun radiation and the space around the sludge thickener to produce the sufficient quantities of dried biosolids.

Biosolids has been dried by establishing a special excavation near the treatment plant, where biosolids have been taken from the thickener and applied to the cavity. Around 1500 liter of liquid biosolids has been used to produce around 30 kg of dried biosolids (Figure 3.13).

Biosolids were collected after 70 days and packed. Biosolids were brought directly to the experiment area and dried for additional 5 days before mixing with soil. Additional drying was applied by grinding the biosolids aggregates to become smaller, and further was then spread on a plastic sheet for 5 days. After final drying, biosolids were collected and prepared to be incorporated as a soil amendment.

Photo 3.13: Sludge drying process

3.3.2.4 Experimental design

Treatments plot were located in the botanical garden in Ramallah city (860 m above sea level). The soil was brought from a non-cultivated land. Soil had been prepared (disaggregated and leveled). The soil was distributed to cover an area of 40 $m^{2,}$ which served as the experiment plots were created. Soil had been compacted and prepared for seeding by application of fresh water to the soil three days before planting. The soil thickness was around 20 cm after compaction. Many measurements have been done to ensure that the soil layer depth is identical around 20 cm in all plots. No other chemical or organic fertilization was applied, and the soil is properly turned and mixed to ensure a uniform soil distribution in all plots.

Treatments plots were prepared by using a traditional tools (land combs, shovel). Each plot had the same dimension. The plot dimensions were made to be the same for all plots, with equal barrier areas between plots. The overall area were divided 20 identical plots of 0.25 m^2 surface area for each plot (0.5 meter length * 0.5 m width). Water was applied five days before planting to be sure that drainage is adequate.

Photo 3.14: Preparation of treatment plots

3.3.2.5 Biosolids application rates

The most important thing during application was to ensure the uniformity of biosolids particulates distribution after mixing, so the impact of any hazardous or beneficial materials will uniform over the entire plot area. Biosolids were applied to the soil in measured quantities according to determined application rates which has been proposed for each treatment; application rates were equivalent to the amount of conventional organic fertilization applied by farmers in the rain-fed plots.

According to the United States federal regulations, the rate of available nitrogen (NH_4-N and NO_3-N) permitted to be supplied by sewage biosolids is limited to 135 kg N/ha every five years. Farmers usually organic fertilizers in the dry form (mainly cattle and poultry manure), and the manure is mechanically mixed with top soil layer by surface plowing. The conventional application rate of non-composted manure is 60 tons per ha in average, and the manure is usually dried before application.

Concerning chemical fertilizers, farers add usually several types, mainly the Di ammonium phosphates (DAP), with average of 2000 kg/ha, and average of 1500 kg/ha from ammonium sulphates $(NH_4)_2SO_4$.

Biosolids are supposed to replace the conventional organic fertilizers, and also to provide a partial alternative for chemical fertilizers. As we don't have a clear image about the most suitable application rates, which can be added to agricultural lands to ensure the desired benefits needed to improve land fertility, and consequently increasing the crop productivity.

On the other hand, maintaining the minimum negative impacts, due to high concentrations of hazardous compounds is another important issue. Accordingly, this experiment had been designed to compare the impacts of biosolids at four application rates of dried biosolids. The distribution of treatments is shown in table 3.2 (see photos 3.15 and 3.16).

Table 3.2: Experiment treatments - biosolids application rates

Treatment	**Application rate in metric tons /ha**	**Application rate in kg /plot ($0.25m^2$)**
1	20	0.5
2	40	1
3	60	1.50
C (control)	0	0

Egyptian clover seeds used in this experiment were produced from the previous season. Seeds were applied according to the recommended seeding rate (100 kg/ha). Seeds were uniformly distributed to cover the total area of each plot.

Seeds were slightly mixed with the soil layer by using soil comb, by this, and subsequently covered with a thin soil layer.

Irrigation was applied using a dribble plastic jug. Each plot received the same water quantity in each irrigation cycle, which ensured that irrigation water will not be a significant factor in production variation. Irrigation water has been applied at periodic intervals depending on weather, crop age and rainfall. A complementary irrigation was added based on the rainfall frequency during the growing period. Applied irrigation water quantities were the same for each treatment plot and it was measured through graduated plastic jug (specially designed for dribble water application). Weeds were removed manually every 2 weeks.

Photo 3.15: Biosolids applied to soil at four loading rates

Photo 3.16: Treatment plots after biosolids mixing and seeds sowing

Finally, Diazinon (70%) where applied to seeds and plots in a concentration of 0.3% (3 ml /l) to prevent seeds damage by ant and other insects.

Irrigation water was applied at the beginning of the growing period in average of three liters per each treatment plot per each irrigation cycle (equals to rate of 12 m^3 /dunum), and with two 2 irrigation cycles weekly.

3.4 Experiment observations

3.4.1 Heavy metals phytotoxicity

Through the process of plant growth and development, toxicity symptoms related to heavy metals concentrations in applied biosolids were recorded. . The assessment of phytotoxicity symptoms was done during the entire season.

The seeds started its germination after 13 days from seeding. Since the toxicity symptoms appear usually on leaves, the appearance of potential toxicity symptoms were monitored starting from the day 30 at the time the first true leaves were completely matured, and one observation was performed each week. Photographs were taken for the investigated plants by a digital camera. Described symptoms in literature were used to characterize metals responsible for injuries.

3.4.2 Impact of biosolids application on growth rate and biomass production

The second observation which has been carried out was for the impact of biosolids application rate on the plant growth rate and development according to certain measurable indicators.

Initially, the visual comparison between plots regarding the biomass quantity and growth intensity was performed, in addition to the overall status o the plants in terms of color, length and size.

According to the nature of the plant, the vegetative growth was assessed by measuring the average plant length, number of complete leaves, and average internodes length. Moreover, the fresh green and dry weights of plants were recorded at the end of the growing season to evaluate the plant productivity per unit area. The weight of the green cut and the dry weight are of high important to assess crop productivity since the whole mowed plants are used for animal feeding.

A complete mowing was performed for plants in each plot. The green plants were weighed for green biomass measurement, and then oven-dried to obtain the dry biomass production. Then, the dry/green biomass percentage for each plot was also measured. The measurements of plant length, number of complete leaves on each plant and the average internodes length were taken once every 10 days.

For measuring plant length and the average internodes space length, the average measurements of five plants which were selected randomly from each plot were used. The same plants were used for counting the number of leaves per plant, in addition to another five plants from each plot; consequently, 10 plants per plot were measured to get more accurate estimations. Leaves of the additional 5 plants were counted without uprooting the plants. Internodes length was measured between the first and second complete leaves. The average of four replicates was also taken to get an estimation of each indicator measurements for each treatment.

For green and dry biomass, the weights of mowed plants for each treatment have been performed, and the average weight of four replicates was taken to give the estimation of each treatment.

The plant growth measurements were taken starting from day 40 of planting till the harvest time (day 100 after planting). Moreover, the internodes length has been measured for each plant, the average measurements for the treatments were also taken as the mean value of all replicates of the treatment

CHAPTER 4

RESULTS AND DISCUSSION

Final presentation of results has been recalculated by applying the dilution factor formulas, and analysis results have been approved only for samples with accepted instrument standard errors. The Instrument detection limits has been also considered in approving the readings; any reading was below the IDL has been excluded.

4.1 Wastewater influent and effluent analysis

By looking to the results shown in tables 4.1 and 4.2, it is clear that the effluent quality is in compliance with heavy metals concentration limits according to the Palestinian standards for effluent reuse in agriculture. The maximum concentration of heavy metals in effluent discharge was used to assess the degree of compliance with effluent reuse standards in Palestine (PS 742/2003) and the FAO guidelines for treated effluent utilization in agriculture (1985).

Table 4.1: Analysis of Influent samples

Parameter	Sampling date							
	15/11/06	**30/11/06**	**10/12/06**	**20/12/06**	**3/1/07**	**15/2/07**	**12/4/07**	**24/4/07**
pH	7.39	7.23	7.64	7.85	7.63	7.54	7.76	7.96
EC (mmhos/cm)	2.71	2.82	2.60	2.23	2.55	2.56	3.04	3.13
T (C°)	19.4	19.1	18.6	17.1	18.8	16.6	19.8	20.2
Heavy metals concentration values in parts per pillions (μg/l)								
B	302.0	158.0	166.0	824.0	224.4	532.0	nd	nd
Zn	958.5	812.0	540.0	3496.0	532.0	3212.0	448.0	916.0
Cu	68.0	108.0	59.2	312.4	131.6	720.0	214.0	157.2
Ni	70.8	44.6	53.6	98.0	117.2	67.6	104.0	46.4
Cr	198.0	154.2	108.4	227.2	160.4	123.2	221.0	113.1
Cd	nd	nd	nd	nd	nd	nd	nd	nd
Pb	nd	nd	nd	nd	nd	nd	nd	nd
As	nd	nd	nd	nd	nd	nd	nd	nd

nd: not detected or obtained measurement was below the instrumental detection limits

Table 4.2: Analysis of effluent samples

Parameter	Sampling date							
	15/11/06	**30/11/06**	**10/12/06**	**20/12/06**	**3/1/07**	**15/2/07**	**12/4/07**	**24/4/07**
pH	7.84	7.56	7.77	7.73	7.62	7.41	7.42	7.73
EC (mmhos/cm)	2.23	2.41	2.45	2.44	2.44	2.46	2.54	2.61
T (C°)	19.3	18.8	18.6	17.2	18.7	16.8	19.5	19.7
Heavy metals concentration values in Parts per pillions (µg/l)								
B	178.0	104.0	224.0	468.0	239.6	182.0	nd	nd
Zn	318.2	244.8	215.0	1480.0	228.0	540.0	248.5	556.0
Cu	52.4	55.3	22.0	187.2	87.2	207.6	175.0	98.4
Ni	28.8	18.1	14.4	47.2	47.6	33.6	32.5	20.5
Cr	67.0	46.0	32.0	89.4	76.8	56.4	51.2	38.6
Cd	nd	nd	nd	nd	nd	nd	nd	nd
Pb	nd	nd	nd	nd	nd	nd	nd	nd
As	nd	nd	nd	nd	nd	nd	nd	nd

nd: not detected or obtained measurement was below the instrumental detection limits

Table 4.3: Descriptive analysis for influent samples

Parameter	N	Range	Minimum	Maximum	Mean	Std. Deviation
pH	8	0.73	7.23	7.96	7.62	0.24
EC (mmhos/cm)	8	0.90	2.23	3.13	2.70	0.29
B (µg/l)	6	666.00	158.00	824.00	367.73	262.57
Zn (µg/l)	8	3048.00	448.00	3496.00	1364.31	1244.45
Cu (µg/l)	8	660.80	59.20	720.00	221.30	217.72
Ni (µg/l)	8	72.60	44.60	117.20	75.27	27.83
Cr (µg/l)	8	118.80	108.40	227.20	163.18	47.58
Cd (µg/l)	N/A	N/A	N/A	N/A	N/A	N/A
Pb (µg/l)	N/A	N/A	N/A	N/A	N/A	N/A
As (µg/l)	N/A	N/A	N/A	N/A	N/A	N/A

Table 4.4: Descriptive analysis for effluent samples

Parameter	N	Range	Minimum	Maximum	Mean	Std. Deviation
pH	8	0.43	7.41	7.84	7.64	0.16
EC (mmhos/cm)	8	0.38	2.23	2.61	2.45	0.11
B (µg/l)	6	364.00	104.00	468.00	232.60	124.59
Zn (µg/l)	8	1265.00	215.00	1480.00	478.81	427.31
Cu (µg/l)	8	185.60	22.00	207.60	110.64	70.12
Ni (µg/l)	8	33.20	14.40	47.60	30.34	12.54
Cr (µg/l)	8	57.40	32.00	89.40	57.18	19.49
Cd (µg/l)	N/A	N/A	N/A	N/A	N/A	N/A
Pb (µg/l)	N/A	N/A	N/A	N/A	N/A	N/A
As (µg/l)	N/A	N/A	N/A	N/A	N/A	N/A

Table 4.5 Recommended maximum concentrations of trace elements in irrigation water according to Palestinian standards and FAO guidelines (Yassin et al, 2008)

Element	Al Bireh WWTP effluent quality (mg/l)	Palestinian limit values (mg/l)	FAO guidelines for Maximum recommended heavy metals concentration (mg/l)
As	nd[1]	0.100	0.100
B	0.470	0.700	0.700
Cd	nd	0.010	0.010
Co	NA[2]	0.050	0.050
Cr	0.090	0.100	0.100
Cu	0.210	0.200	0.200
F	NA	ND[3]	1.000
Fe	NA	5.000	5.000
Mn	NA	0.200	0.200
Hg	NA	0.001	0.001
Ni	0.050	0.200	0.200
Pb	nd	0.100	5.000
Se	NA	0.020	0.020
Zn	1.480	2.000	2.0

[1]nd not detected
[2]NA not determined
[3]ND not available

According to the comparison in table 4.5, copper is the only metal which is slightly exceeded the concentration limits for Palestinian standards and FAO guidelines. Accordingly, it is clear that the effluent of AWWTP complies with both standards in terms of maximum concentrations of heavy metals for effluent to be reused in agriculture; although Cu concentration is problematic and should be addressed before reuse, could be through dilution with fresh or brackish water.

For lead and cadmium, the recorded concentrations were below the detection limits of the analysis instrument, so all analysis results for these two metals were not recorded.

4.2 Heavy metals mass balance

The mechanism for daily heavy metal mass quantification in influent and effluent was performed using the analysis results and average flow rate at the sampling days. The mass of each heavy metal discharged to the aeration bonds were measured and compared to the mass disposed with effluent in order to get estimations of heavy metals mass balance and quantities which are supposed to be retained in biosolids.

The flow rate in the each sampling day was recorded by the installed flow meter. The effluent flow rate was considered theoretically the same as the influent flow rate, since there is no daily measurement facility for the outflow at Al Bireh WWTP. The difference between the two values is considered by default as the mass which retained in biosolids and will be existed in biosolids composition. This calculation give us an indicator about the removal efficiency of heavy metals during the treatment process and can provides a kind of initial assessment of potential retained mass of each heavy metal in biosolids, which can give some approximation about metals concentration in biosolids and its contamination potentials for surrounding agricultural lands where biosolids are disposed.

Mass balance for each detected heavy metal (Zn, Cu, Ni, Cr, and B) was measured and recorder in tables A-1 to A5 in annex 1. Based on the flow measurement and measuring the estimated retained mass in biosolids for each metal according to the concentrations difference in the influent and effluent. The heavy-metal mass balance provided an idea regarding the status of heavy metals flow, the removal potential and the percentage of removal as precipitated complexes retained in biosolids which finally disposed to surrounding areas.

According to the results shown in tables A-1 to A-5 in Annex 1, the net retained mass loads of heavy metals in influent and effluent discharge were found to be as follows

- For Boron: the ratio of retained mass was between 34.2-65.8% of total boron mass entered with the influent, and the average of retained biosolids mass percentage was 46.08 %.
- For Zinc (Zn): the ratio of retained mass was between 39.3-83.2% of total boron mass entered with the influent, and the average of retained biosolids mass percentage was 66.2%.
- For Copper (Cu): the ratio of retained mass was between 18.2-62.8% of total boron mass entered with the influent, and the average of retained biosolids mass percentage was 52.2%.

- For Nickel (Ni): the ratio of retained mass was between 50.3-73.1% of total boron mass entered with the influent, and the average of retained biosolids mass percentage was 61.6%.
- For Chromium (Cr): the ratio of retained mass was between 52.1-76.8% of total boron mass entered with the influent, and the average of retained biosolids mass percentage was 65.3%.
- Regarding lead (Pb), Cadmium (Cd) and Arsenic (As), these metals were not detected in any of analyzed samples. Therefore, no mass balance calculations were performed for these metals.

Figure 4.1 provides more clear comparison between heavy metals in respect to their percentages in retained mass in the biosolids of the overall mass entered to the treatment plant in the influent discharge, while a comparison of mass balance status for different heavy metals are presented in figure 4.2.

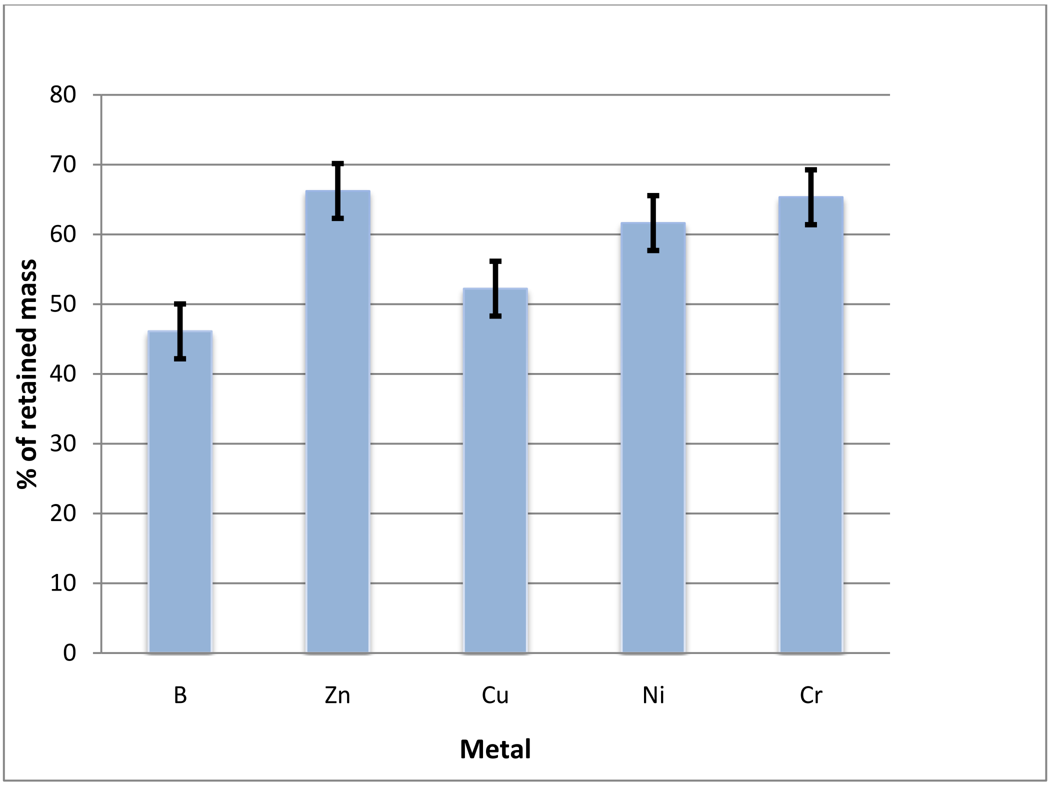

Figure 4.1: Average ratio of retained mass in Biosolids for each detected heavy metal.

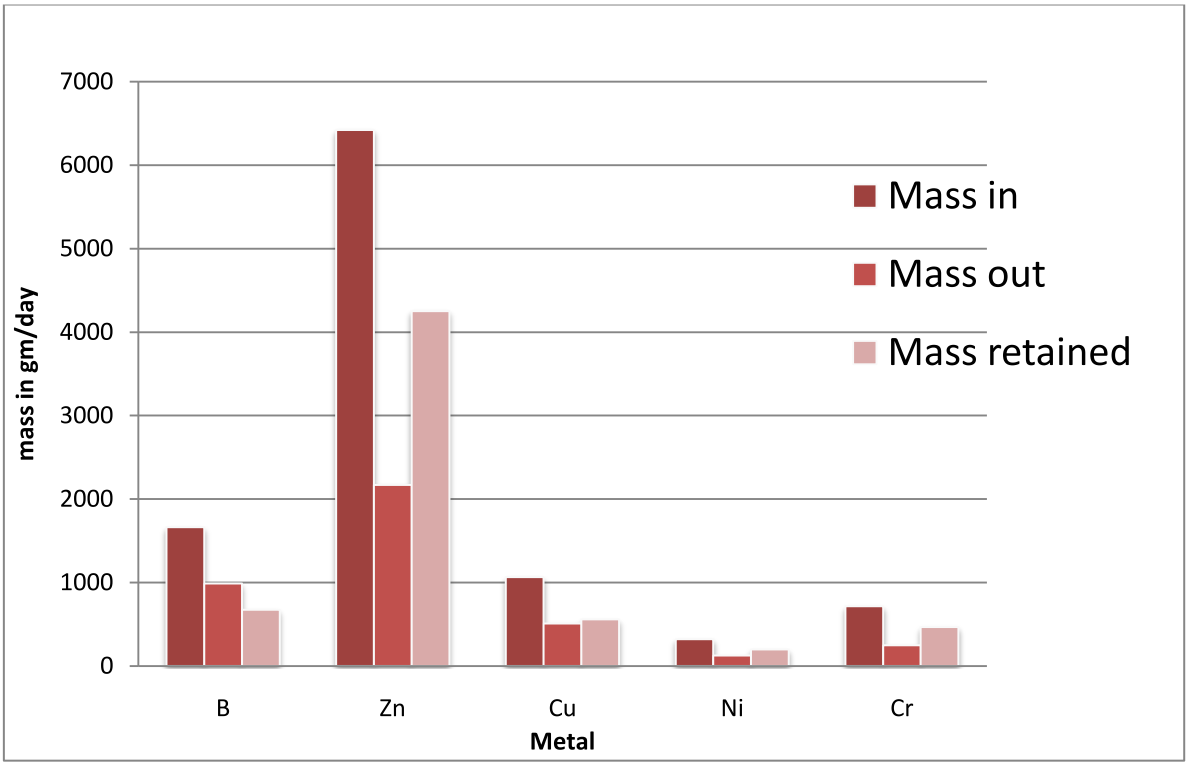

Figure 4.2: Average daily mass balance status of analyzed heavy metals

4.3 Biosolids characterization and ICP-AES analysis

Table 4.6 shows the obtained results for both primary analysis and ICP-AES heavy metals determination for ten analyzed biosolids samples. According to these data, it was possible define the biosolids main characteristics and its quality in terms of permissible heavy metals concentration limits compared with other standards presented in this study.

4.3.1 Basic biosolids characteristics

Table 4.7 provides descriptive analyses of biosolids samples. From these results, the following main characteristics of investigated biosolids samples were recorded:

4.3.1.1 pH value

According to the results shown in tables 4.11 and 4.12, the average pH value was around 6.38, which indicates its acidic nature. Mainly it is the preferred form to apply to agricultural land in Palestine, since most areas are characterized by high alkalinity which causes many problems, mainly in iron and magnesium availability. Adding biosolids will improve soil pH status and may increase the bioavailability of many micronutrients to crops.

4.3.1.2 Salinity (EC value)

Electrical conductivity for analyzed samples was ranged between 2.43-4.13 mmhos/cm, with an average of 3.43 mmhos/cm. This salinity values are considered normal if compared to the other organic and chemical fertilizers

4.3.1.3 Solids content

- **Total solids content (TS)**

According to the performed analysis, liquid biosolids of Al Bireh WWTP has an average total solids content of 27.24 g per liter, and in terms of percentage it is around 2.72 %. This value means that each 1000 liter of biosolids contain an average of 27.24 kg of totally dried biosolids. Accordingly, the average annual production of dried biosolids by Al Bireh WWTP is around 550 tons (see section 1.3.2). This value is still estimated since the variation of solids content in biosolids can significantly affect these values, in addition to the variation of biosolids disposal within different seasons.

- **Total suspended solids and total dissolves solids (TSS and TDS):**

From measured total solids, TSS consisted around 87.3% - 90% of total solids in biosolids where the suspended solids content has varied between 18.940 g/l and 28.050 g/l, while the TSS% in samples ranged between 1.9% and 2.8%.

Total dissolved solids were around 10-12.7% of total solids content in biosolids samples, which represents around 0.13-0.31% in terms solid percentage in 1 biosolids sample. Usually, the production of biosolids was estimated by the average total suspended solids in the sample where dissolved solids could be lost during applied drying methods.

- **Total volatile suspended solids (TVSS)**

TVSS content in biosolids is a regarded indicator for organic matter fraction in dried biosolids. The value of TVSS ranged between 15.270 g/l and 23.540 g/l (1.53 %-2.35%), with an average of 20.708 g/l (2.07%) in liquid biosolids sample. Volatile suspended solids formed between 70.4%-75.5% of total solids content in the samples which indicates rich organic matter content in dried biosolids.

4.3.2 Heavy metals concentrations

Results in tables 4.11 and 4.12 indicate that Zinc (Zn) is the most heavy metal contaminating the biosolids of Al Bireh WWTP. It existed in all samples in concentrations ranged between 292 - 1150.3 mg/kg dry weight. This is considered a relatively high concentration compared to other investigated metals. Copper (Cu) came in the second place; it was detected in all samples with concentration values in biosolids samples ranged between 106.8-411 mg/kg dry weight. Increasing the concentration levels for Zn and Cu could be due to the existence of many resources discharging these metals, such as pipes and taps, which can significantly increase the concentration of these metals in sewerage networks and consequently in the influent discharged in the treatment plant (refer also to table 1.3). For other detected metals, Chromium (Cr) was the third in terms of its concentration values. It was detected in all samples. Chromium concentrations ranged between 24.2-232 mg/kg dry weight with a large variation in concentration between samples.

For Nickel (Ni), the concentration values ranged between 13.6 - 115.7 mg/kg dry weight and it was detected also in all samples. The case of Boron is somehow different, where it was detected only in 3 samples (out of 10). The concentration of Boron (B) has ranged between 29.4 and 58.8 mg/kg dry weight.

In respect to Lead (Pb) and Cadmium (Cd), both existed in relatively low concentrations compared to other metals. This could be due to their limited potential sources, where very limited business generated effluent rich with those metals. The concentration values ranged between 0-62.6 mg/kg dry weight for lead and 0-9.94 mg/kg dry weight for cadmium. Concerning Arsenic (As), this metal was not detected in any sample, neither in influent or effluent wastewater samples.

Table 4.6: Analysis results of biosolids samples

Parameter	Sampling date									
	15/11/09	**30/11/06**	**10/12/06**	**20/12/06**	**3/1/07**	**15/2/07**	**12/4/07**	**24/4/07**	**12/6/07**	**24/6/07**
Physiochemical parameters										
pH	6.88	6.62	6.76	6.72	6.18	6.34	6.18	6.52	6.91	6.38
EC	3.87	3.46	2.43	3.31	3.34	2.78	3.34	3.98	3.65	4.13
T	19.8	19.6	17.2	18.9	17.4	17.0	17.4`	20.7	22.2	24.7
TS (g/l)	24.78	21.68	26.67	26.48	28.37	24.88	29.50	30.49	28.47	31.17
TDS g/l	2.97	2.74	1.29	2.26	2.32	1.37	2.14	2.97	2.83	3.12
TVSS	17.34	15.27	20.96	20.86	21.95	18.80	23.44	23.15	21.78	23.54
Heavy metals concentration value In mg/kg dry weight										
B	N/A*	58.80	N/A	29.4	N/A	36.4	N/A	N/A	N/A	N/A
Zn	1150.30	368.20	612.50	515.10	764.30	641.00	400.50	292.00	684.00	633.40
Cu	411.40	187.00	406.00	106.80	334.00	167.60	243.40	117.20	190.00	202.80
Ni	98.40	61.40	115.70	15.20	52.30	17.80	28.40	13.60	32.70	42.80
Cr	180.00	134.60	232.00	24.20	85.00	41.70	61.40	43.60	82.50	95.60
Cd	5.64	3.48	9.94	nd **	3.00	1.44	2.56	7.34	6.40	8.66
Pb	62.60	nd	1.66	16.50	28.80	19.20	26.80	2.52	4.16	3.76
As	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

*N/A : Not available

**nd: Heavy metal was not detected by the instrument.

Table 4.7: Descriptive analysis of biosolids samples

Parameter	N	Minimum	Maximum	Mean	Std. Deviation	Variance
pH	10	6.18	6.91	6.55	0.27	0.07
EC (mmhos/cm)	10	2.43	4.13	3.43	0.53	0.28
TS g/l	10	21.68	31.17	27.24	2.93	8.60
TDS g/l	10	1.29	3.12	2.40	0.66	0.43
TSS g/l	10	18.94	28.05	24.85	2.84	8.05
TVSS g/l	10	15.27	23.54	20.71	2.76	7.64
B (mg/kg)	3	29.40	58.80	41.53	15.36	235.86
Zn (mg/kg)	10	292.00	1150.30	606.13	243.83	59451.24
Cu (mg/kg)	10	106.80	411.40	236.62	110.77	12269.33
Ni (mg/kg)	10	13.60	115.70	47.83	35.18	1237.53
Cr (mg/kg)	10	24.20	232.00	98.06	66.12	4372.18
Cd (mg/kg)	9	1.44	9.94	5.38	2.94	8.67
Pb (mg/kg)	9	1.66	62.60	18.44	19.64	342.10
As (mg/kg)	0	0.00	0.00	0.00	0.00	0.00

4.4 Determination of biosolids quality compared to other biosolids standards

By looking to the results in the previous section, it is possible to develop a certain comparable quality parameters for biosolids of Al Bireh WWTP, in order to be able to assess the applicability of biosolids to be used as organic fertilizer. For instance, it is possible to condense the results of biosolids characterization analysis and the ICP-AES analysis for heavy metals to establish biosolids quality tables, which will facilitate the comparison with other standards and regulations.

For biosolids physiochemical characterization, mean values for measured parameters were used to establish biosolids main characteristics (table 4.8).

Regarding heavy metals concentration (ceiling concentrations), the maximum detected values were considered as the ceiling concentrations of heavy metals in biosolids of Al Bireh WWTP. Accordingly, the ceiling concentration limits of heavy metals were determined (table 4.9).

Table 4.8 Physiochemical characteristics of Al-Bireh wastewater treatment plant biosolids

Parameter /unit	Mean values
pH	6.55
EC (mmhos/cm)	3.43
TS g/l	27.25
TDS g/l	2.40
TSS g/l	24.85
TVSS g/l	20.71

According to the EPA regulations, biosolids can be applied to soil when analysis results complied with maximum concentration limits identified in the guidelines. This means that each analysis should not exceed the ceiling concentrations in order to allow the agricultural utilization of biosolids.

Table 4.9: Maximum HM concentrations of Al Bireh WWTP biosolids

Metal	Ceiling concentrations in mg/kg dry weight
Zn	1150.30
Cu	411.40
Ni	115.70
Cr	232.00
Cd	9.94
Pb	62.60
As	N/A

The comparable standards which were used in this study are: US-EPA biosolids land application standards (table 4.10), Israeli standards for biosolids application to agricultural land (table 4.11), and the EU directive for controlling land application of biosolids (EU Directive 86/278 EEC) table 4.12.

Table 4.10: EPA's pollutant limits for land applied biosolids (USEPA)

Metal	Ceiling Conc. mg/kg	Conc. Limits for "clean" biosolids mg/kg
As	75	41
Cd	85	39
Cr	3000	1200
Cu	4300	1500
Pb	840	300
Hg	57	17
Mo	75	18
Ni	420	420
Se	100	36
Zn	7500	2800

Table 4.11: Israeli standards for biosolids utilization in agriculture (Israeli Ministry of Environmental Protection, 2008)

Metal	mg/kg total solids
Cd	20
Cu	600
Ni	90
Pb	200
Zn	2500
Hg	5
Cr	400

Table 4.12: EU regulations for biosolids land application (Directive 86/278 EEC)

Metal	Mg/kg dry matter
Cd	40
Cu	1750
Ni	400
Pb	1200
Zn	4000
Hg	25
Cr	N/A

Table 4.13: Comparing the values of found heavy metals ceiling concentrations in AWWTP biosolids of heavy metals with other standards

Metal	Allowed Ceiling Concentrations in mg/kg Dry weight			
	Al Bireh	**EPA_USA**	**Israel**	**EU**
Zn	1150.30	7500.00	2500.00	4000.00
Cu	411.40	4300.00	600.00	1750.00
Ni	115.70	420.00	90.00	400.00
Cr	232.00	3000.00	400.00	NA
Cd	9.94	85.00	20.00	40.00
Pb	62.60	840.00	200.00	1200.00
As	N/A	75.00	N/A	NA

This comparison is further clarified in figure 4.3. It is very clear that the maximum concentration limits of heavy metals found in biosolids produced by Al Bireh WWTP were below the ceiling concentrations defined in all comparable standards, except the case of Nickel (Ni), where the concentration limits in the Israeli standards were slightly less than the maximum concentration limits found in analyzed samples whereas it was more in EPA standards and EU directives. Accordingly, biosolids of Al-Bireh WWTP are suitable for land application in terms of HM contents.

4.5 Heavy metals phytotoxicity observation

The daily visual observation did not recognize any common symptom for heavy metals toxicity, during 100 days of growth until the crop harvest. Plants did not show any abnormal symptoms, which reflected any kind of toxicity related to Boron or heavy metals phytotoxicity, even for the treatment of the highest application load of biosolids (60 tons /ha).

The potential phytotoxicity symptomes related to heavy metals exsesive concentration in soil has been examined refering to the descriptions and photoes showing the distinctive toxicity symptoms caused by each metal. It is important to mention that these observations indicated the visual assessment of heavy metals phytotoxicity, while the possibility for heavy metals accumulation inside the plants tissues or the mobility status of different heavy metals between plant soils interfaces should be subjected to further investigation.

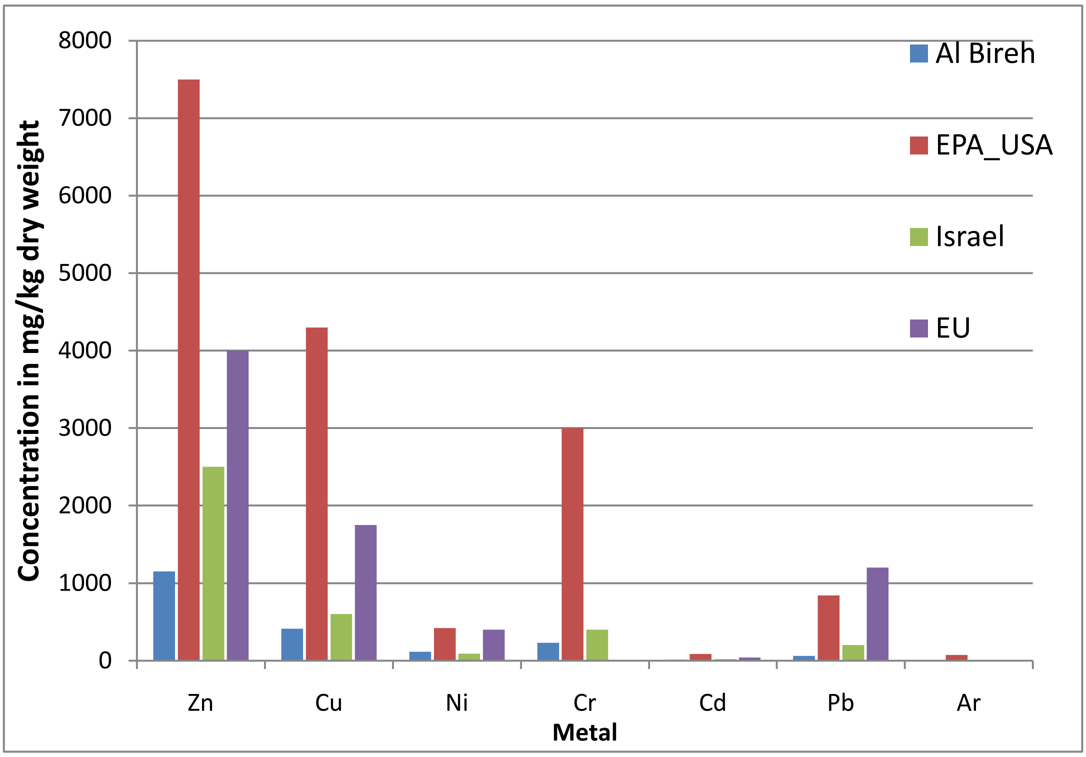

Figure 4.3: Comparing the values of found heavy metals ceiling concentrations at Al-Bireh WWTP Biosolids of heavy metals with other standards

4.6 Visual assessment of plant growth

Regarding the growth rate assessment parameters**,** photos 4.1 - 4.4 show the growth in four subsequent periods (20 days between each observation), starting from day 40 of planting till day 100, directly prior to plant mowing.

Photo 4.1: Plant growth rate visual observation for experiment treatments 40 days after planting

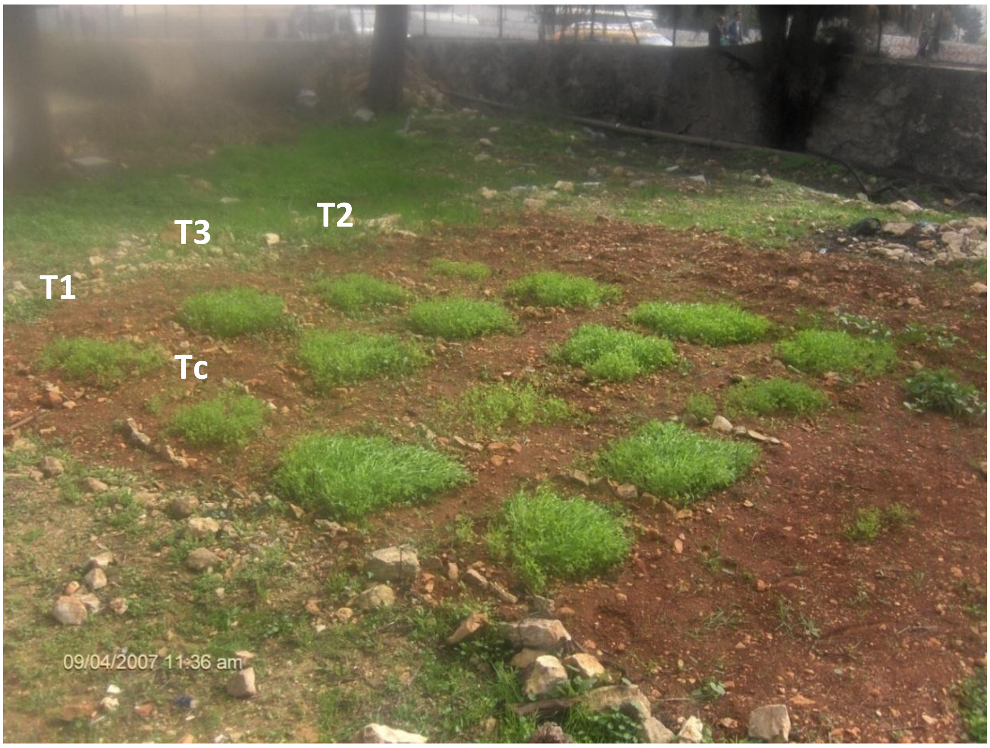

Photo 4.2: Growth rate visual observation for experiment treatments 60 days after planting

Photo 4.3: Growth rate visual observation for experiment treatments 80 days after planting

Photo 4.4: Plant growth rate visual observation for experiment treatments 100 days afte planting

The visual growth rate observation has been documented through photographs. The noticeable variation in plant growth rate is very obvious. The visual observation clearly indicate the impact of biosolids application on crop growth rate after 40 days of planting, and this visual difference became more distinctive by time.

According to the visual observation, clear and distinctive variation in plant growth and development has been noticed between treatments. Plant growth was more rapid and intensive in plots received the highest application loads (40 and 60 tons of dry biosolids /ha), and variation became more distinctive by time, where it seems that the growth rate has positively affected by applying biosolids.

4.7 Observations of growth and biomass production

4.7.1 Plant growth indicators

This included the following growth parameters: Plant length, number of true leaves and the average internodes length. Plant length and the number of true leaves are the main measured parameters assessing the impact of biosolids application rate on growth and development of plants. Tables A-6 to A-12 in Annex 2 provide the recorded results of plant length and number of complete leaves in each replicate and the treatments average value for each performed measurement.

Results show that there is a direct positive relationship between biosolids application rate and plant growth rate (reflected by its length and the number of true leaves). Photos 4.5, 4.6, 4.7 and 4.8 show the measured variation in length and number of true leaves.

The growth rate variation was observed during the entire growth period. Results show clearly that growth parameters were best with plots received the highest biosolids application rate. Figure 4.4 shows the difference in plant length between treatments; figure 4.5 shows the development of plant length over the growth period, whereas figure 4.6 shows a comparison of plant length between treatments on the day 40 and the day 100 (harvest time).

The growth parameters are in direct relation to the average biomass production (see section 4.7.3), as theses parameters are clearly related to the plant size, biomass and the productivity of the crop.

The average number of true leaves increase significantly upon biosolids application (Table 4.14). Figures 4.7 shows difference in number of leaves at the time of harvest, whereas figure 4.8 shows the changes in number of leaves number leaves over the growing period. A comparison in respect to number of leaves in day 40 and day 100 of planting is shown in figure 4.9.

The measurement of internodes length provides an indicator about the shoot elongation and the bending tendency. In this experiment, a direct relationship exists between the average internodes length and the plant length (growth rate). Consequently, longer plants had longer internodes. It was clear that the internodes length between the first and the second nodes has a direct correlation to the total plant height. The value of internodes length was also an indicator of the impact of biosolids application.

Further, a significant variation was found between the 2nd and the 3rd treatments and the control treatment, although this did not affect the plant erection status. Figure .10 shows the comparison of internodes length between treatments at the time of plant harvest.

Tables 4.14 shows plant length, number of leaves and internodes length for experiment treatments at the time of harvest.

Table 4.14: Plant growth measurements

Biosolids Load in Tons/ha	**Measurements of Plant growth indicators at harvest time (p = 0.05)***		
	Average plant length in cm	**Average Number of leaves/plant**	**Average plant internodes length (cm)**
0	28.200 a	5.000 a	8.40 a
20	36.475 b	5.450 b	12.50 b
40	40.825 c	5.900 c	16.80 c
60	42.700 c	5.975 c	17.10 c

*****For each treatment, means follows by the same letter do not differ significantly at 5 % probability level.

Photo 4.5: Measurement of the average plant length for each single plot

Photo 4.6: Visual comparison of plant size for different treatments. Treatments from the left to the right (60 tons/ha, 40 tons/ha, 20 tons/ha and the control)

Photo 4.7: Visual comparison in size of plants taken from control treatment (left) and plants of the highest Biosolids application rate treatment (right)

Photo 4.8: Plant length comparisons directly before harvest. Treatments from left to right, 60 tons/ha, 40 tons/ha, 20 tons /ha and the control.

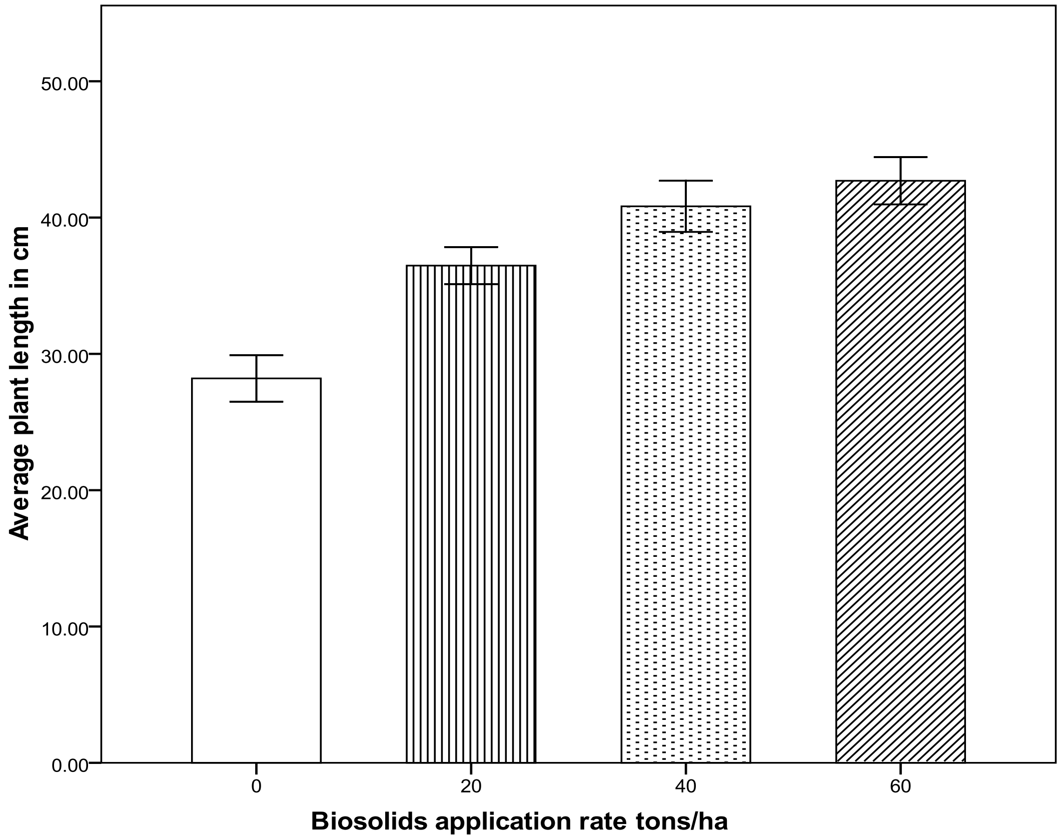

Figure 4.4 Average plant lengths at day 100 of planting

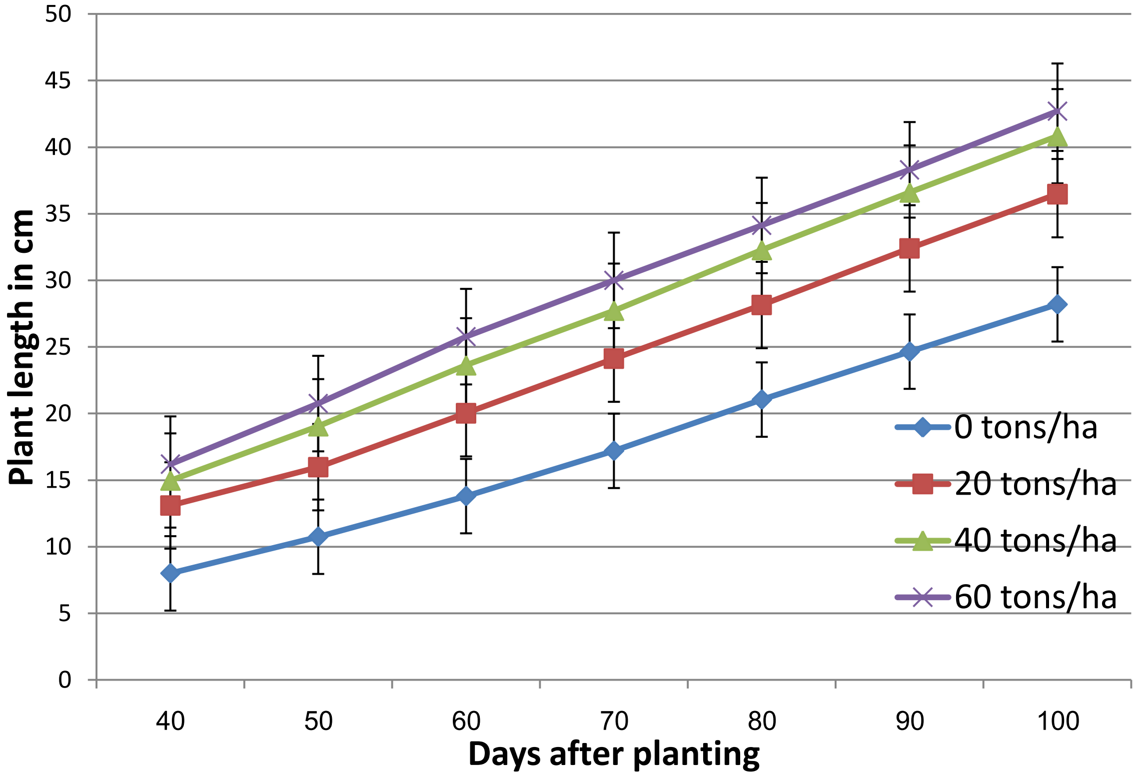

Figure 4.5 Changes in plant hight over the growing period

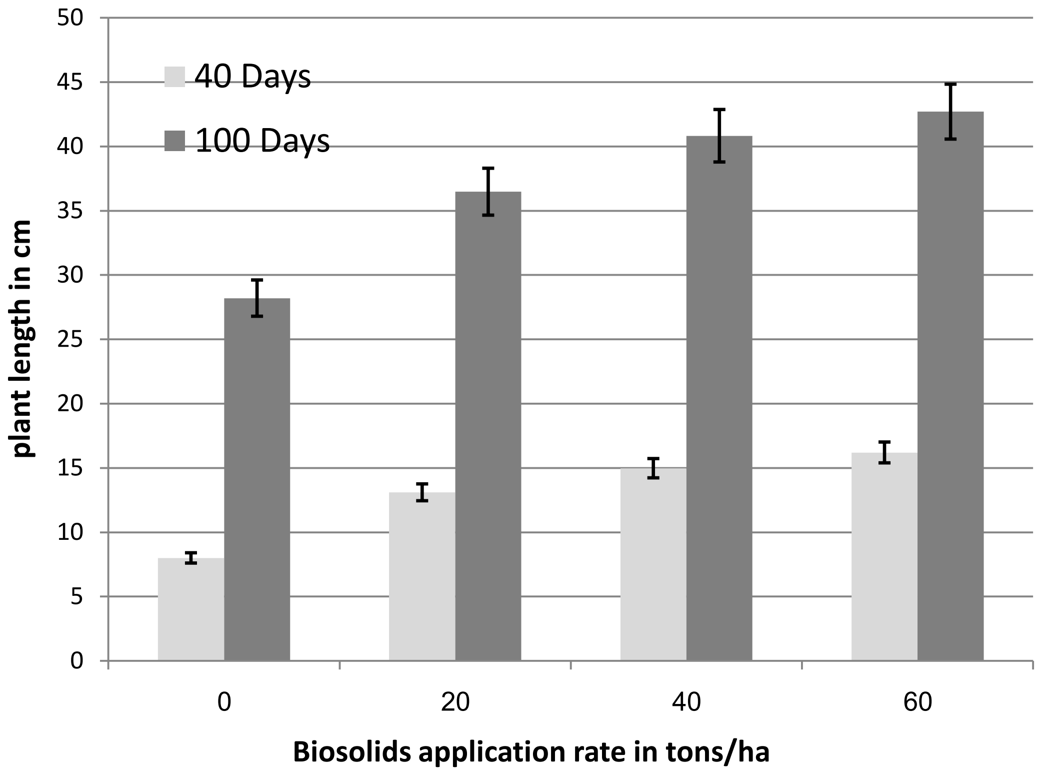

Figure 4.6: Comparing plant length increase on day 40 and day 100 (prior plant mowing).

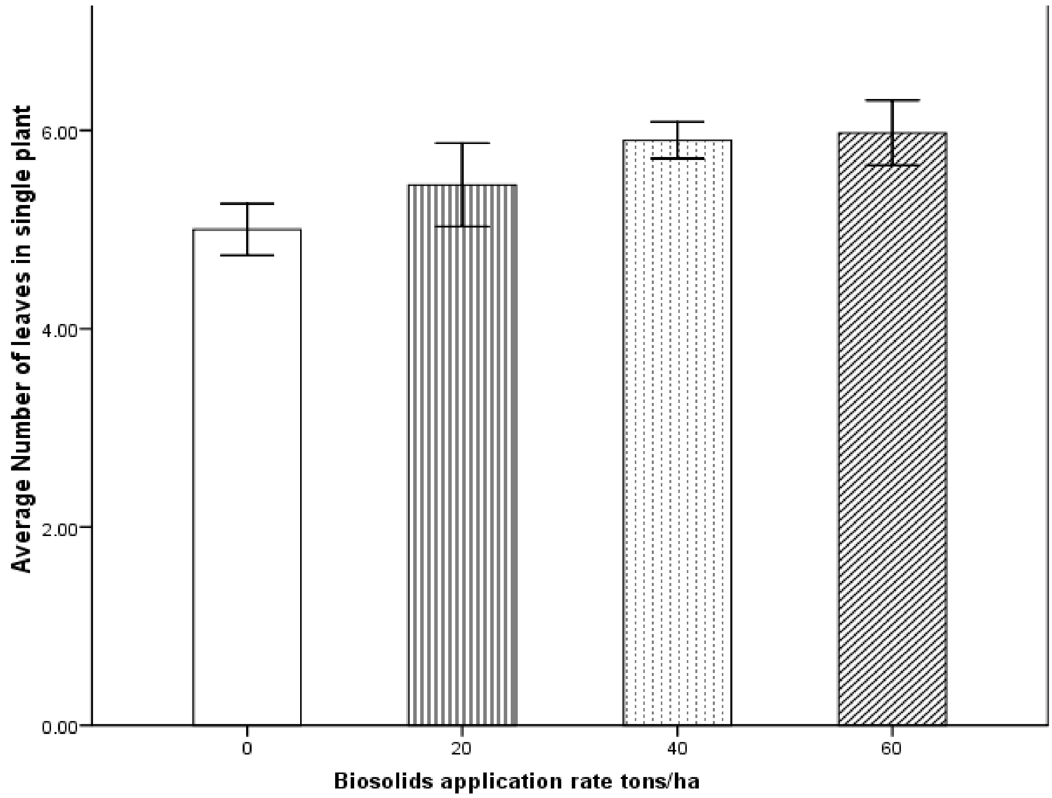

Figure 4.7: Average number of leaves per single plant in each treatment

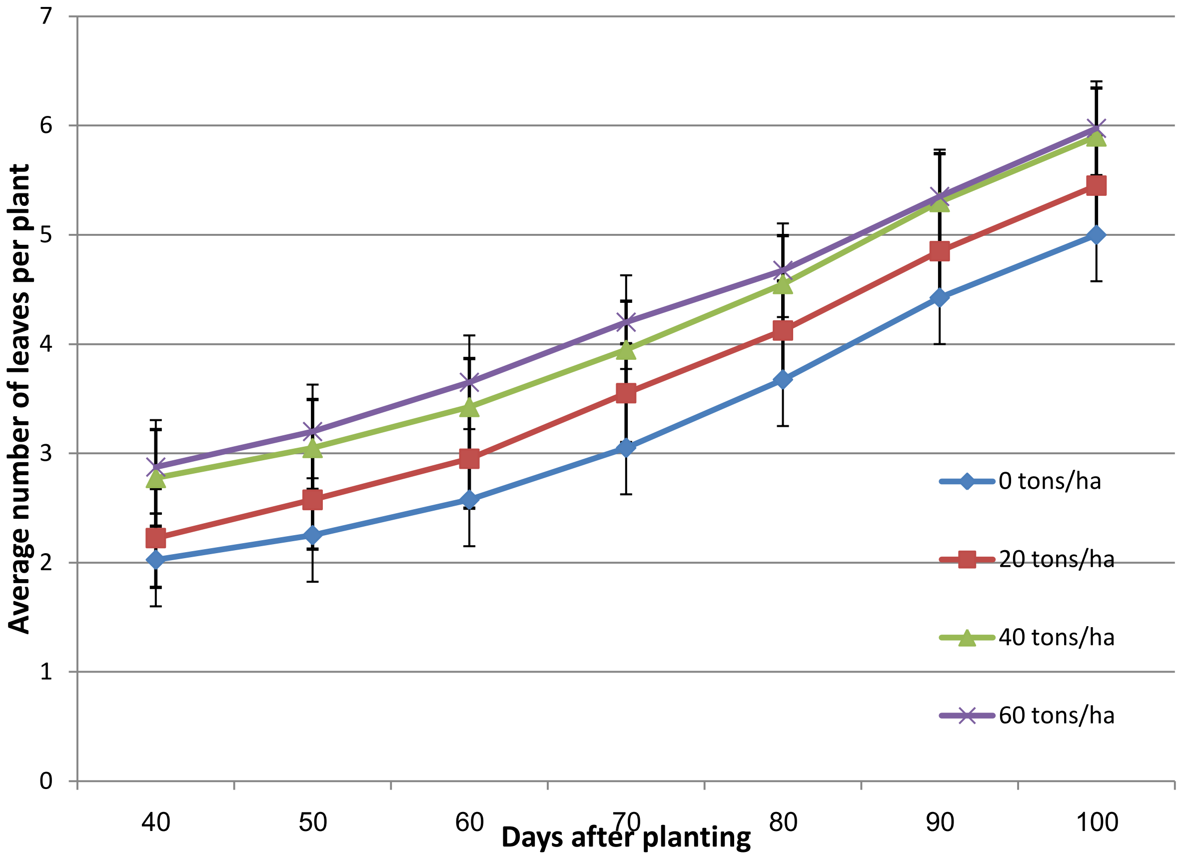

Figure 4.8: Development of leaves number over the plant growth period

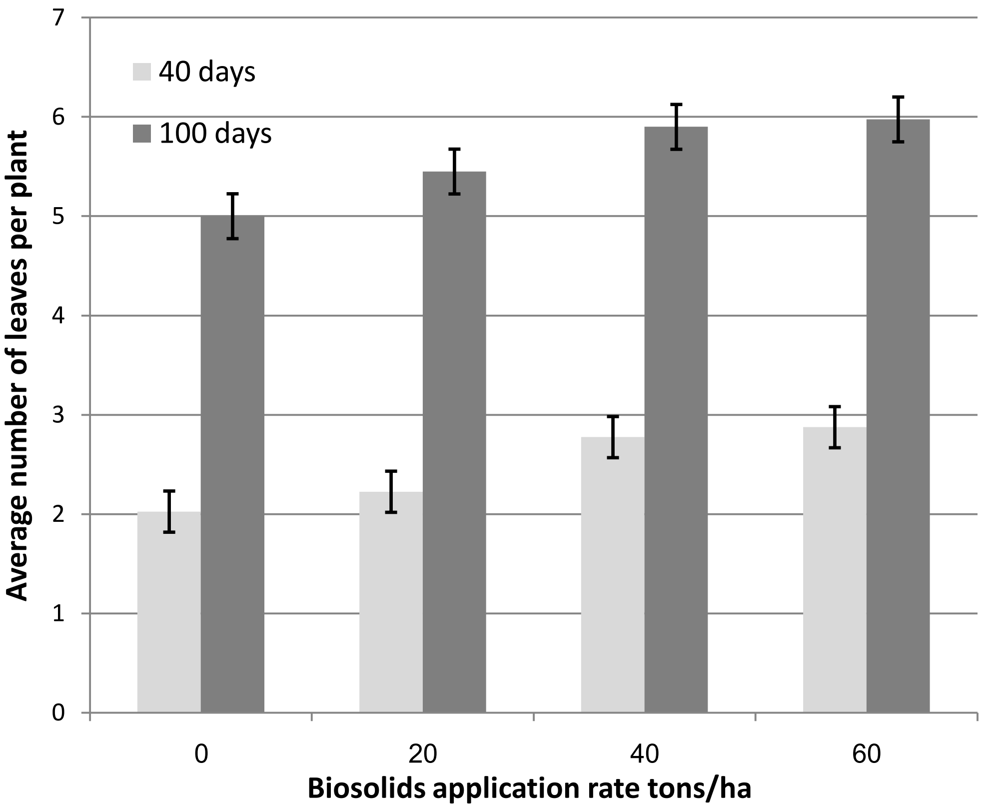

Figure 4.9: Comparing number of leaves increase at 40 and 100 days of planting

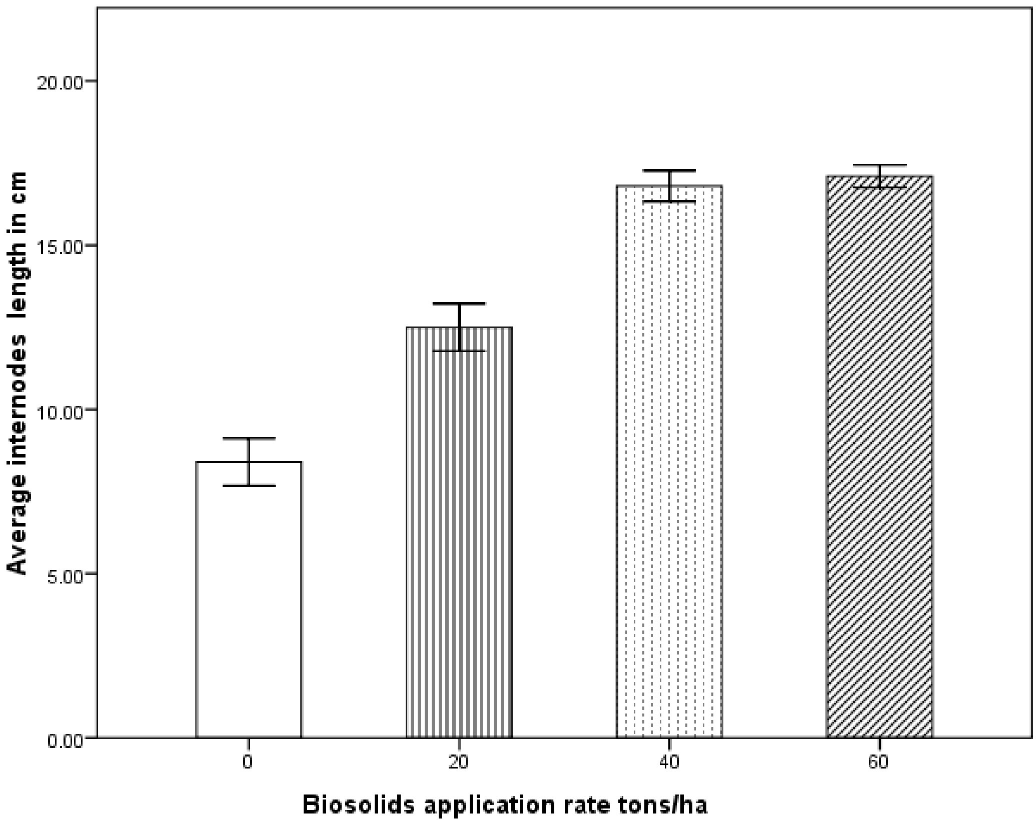

Figure 4.10 Average internodes length between treatments at the time of plant harvest

Statistical analysis shows a significant difference in the plant height at the time of harvest (day 100). Applying dried biosolids had significant impact on plant growth, as a significant increase in plant height occurs. Moreover, there were significant differences in plant height between the 20 tons/ha biosolids loading rate and both 40 and 60 tons/ha biosolids loading rate.

Moreover, statistical analysis shows that there were significant differences regarding average number of leaves. This result indicated that the higher growth rate in the highest biosolids loading induces formation of more leaves, which induces more biomass production (see tables 4.15 and 4.16).

4.7.2 Biomass production

Plants were harvested (mowed) after 100 days of planting. This feed crop is a winter annual legume usually harvested one time or twice depending on the rain season, Egyptian clover is usually harvested starting from the day 80 from sowing, this depends on the growth rate that effected by the weather conditions, soil fertility and rainfall rate and distribution, (Miller et al., 1989).

In this experiment, no additional fertilization was applied, and the plants were left till the day 100 after sowing. Mowing process done early in the morning (9:00AM) using a special cutting scissors and the plants were mowed to less than 1 cm height. Plants were mowed without applying water for irrigation in the last 24 hours before mowing, and then were cleaned from any other plants (weeds) that can affect the biomass measurement. Mowed plants were collected in clean transparent plastic sacks, sealed and directly transported to the laboratory to measure the green and dry biomass production.

The average green biomass weight was calculated for each treatment to evaluate the difference between all treatments. Regarding the dry biomass, the plants from all experiment plots were dried completely by incubation in the furnace at 105°C for 1 week; the plants were then removed and weighted again.

Table 4.15 shows that the highest green and dry biomasses was recorded in treatment 3 (60 tons/ha biosolids application rate) with an average of 833.8 and 92.86 g/plot consequently, while the lowest produced green and dry biomasses was recorded with in the control treatment with an average of 192.4 and 21.47 g/plot consequently.

In table 4.16, the green and dry biomass production was estimated in kg/ha.

Table 4.15: Biomass production values

Biosolids application rate tons /ha	**Average biomass production in g (p=0. 05)**		**Dry/green biomass %**
	Green biomass	**Dry Biomass**	
0	192.40 a	21.47 a	11.16 a
20	436.10 b	49.46 b	11.34 a
40	739.25 c	78.05 c	10.56 a
60	833.80 c	92.86 c	11.14 a

Table 4.16: Biomass modified to kg /ha

Biosolids application rate tons /ha	**Average biomass production in kg/Ha**	
	Green biomass	**Dry Biomass**
0	7696.0 a	858.8 a
20	17444.0 b	1978.4 b
40	29570.0 c	3122.0 c
60	33352.0 c	3714.4 c

Figures 4.11 and 4.12 below provide better comparison in green biomass and dry biomass production between the experiment treatments.

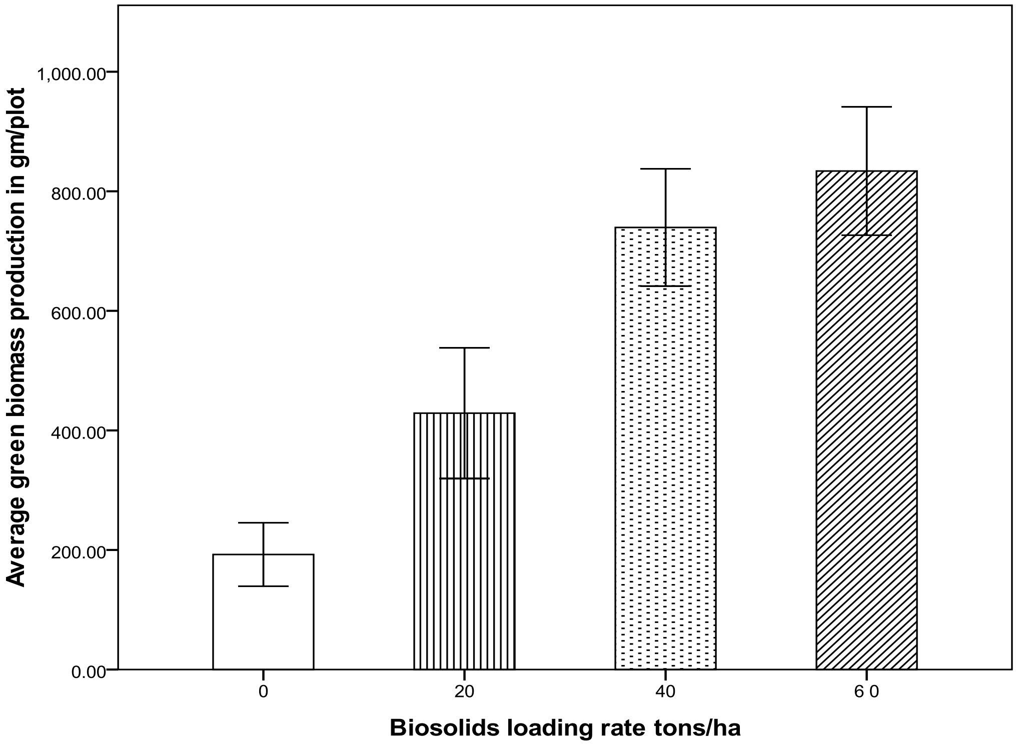

Figure 4.11 Average green biomass production (gm)

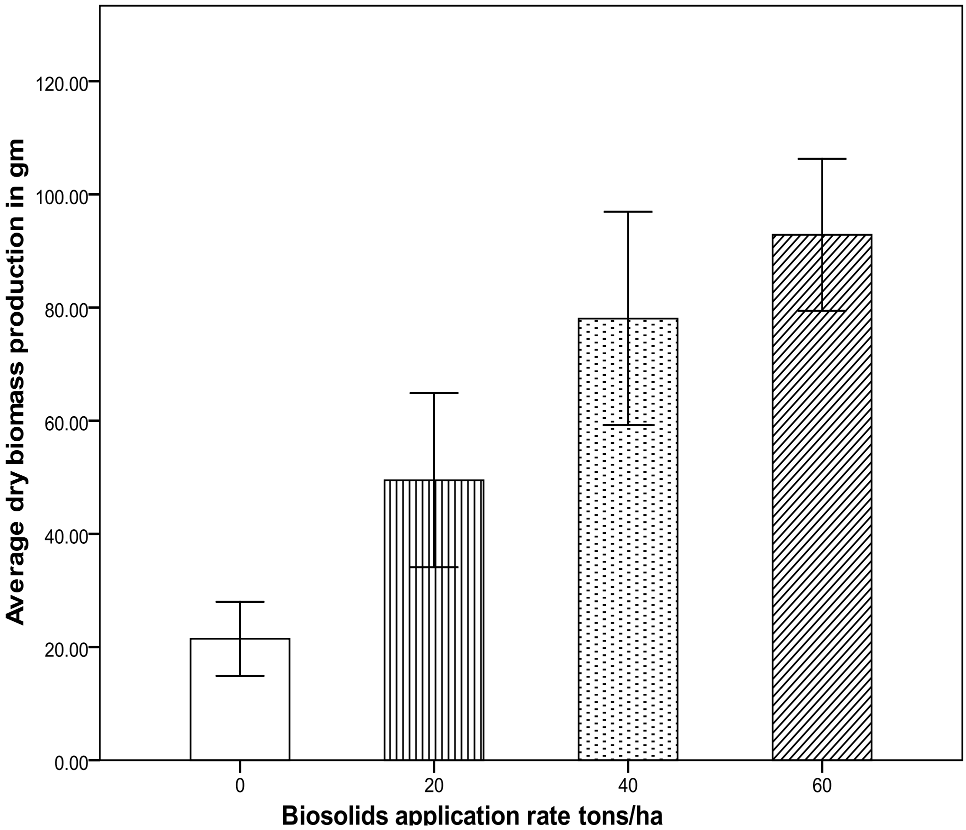

Figure 4.12 Average dry biomass productions (gm)

The results indicated that the application of AWWTP biosolids to soil grown with Egyptian clover at a rate up to 60 tons/ha increased green biomass and consequently dry biomass production significantly. However, applying biosolids at any rate increased biomass production of Egyptian clover significantly.

By comparing the dry biomass /green biomass percentage for the harvested plants, we found slight variation between treatments. Although no significant differences were found n dry/green biomass percentage in all treatments, this ratio ranged between 10.56 and 11.34 percent (table 4.15).

Figure 4.13 shows better comparison regarding the dry/green biomass percentage for all treatments.

According to these results, significant variation in plant length, number of true leaves per plant and the internodes length between treatments which provides strong indication for the positive impact of biosolids application on growth and development of Egyptian clover. It has been noticed that there was a direct correlation between biosolids loading rate and various growth parameters.

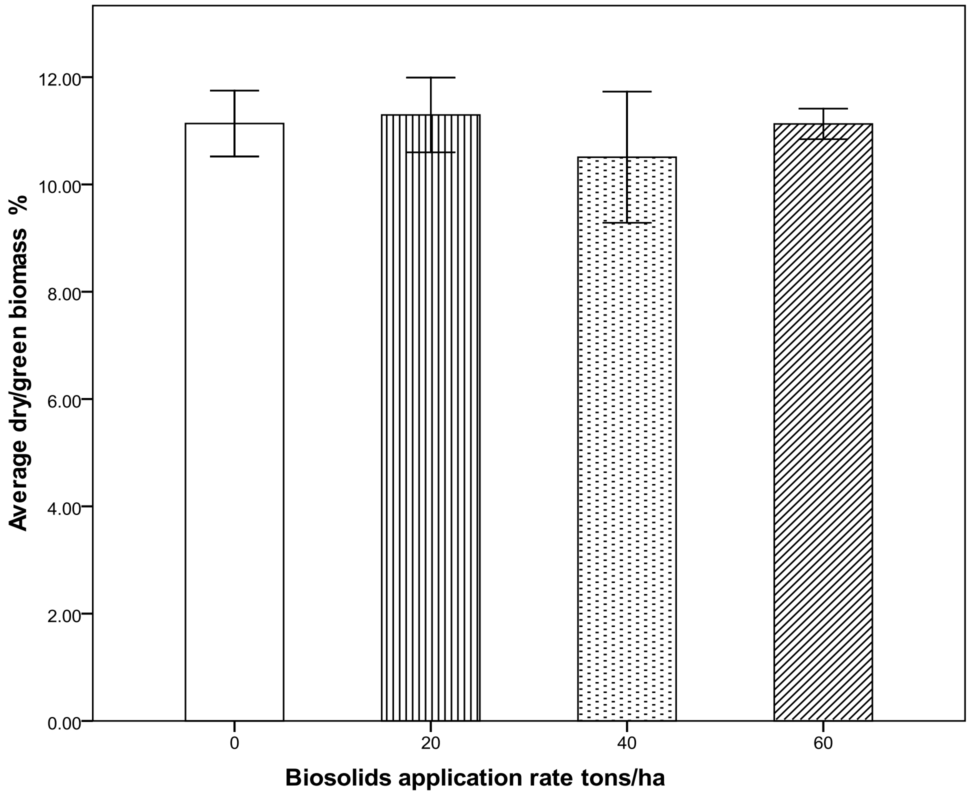

Figure 4.13: Dry /green Biomass % for each treatment

Actually, the variation between the control plants and plants received the highest application rate was very high in terms of all investigated parameters. For instance, the plant length ratio between these two treatments was 1.51:1 at harvest time while the ration of leaves number was 1.2:1 between these two treatments.

Regarding the biomass production, the treatment with the highest application rate gave the maximum production quantity from green and dry biomass (3335.2 kg/dunum in average), if compared with the control treatment (769.6 kg/dunum), the ratio will be 4.33:1 which indicated the presence of regarded difference in crop productivity. This significant variation is mainly a consequence of the difference in the overall shoot size of single plant including the size of leaves and the stem trickiness, these differences can be clearly observed in photos 4.3 to 4.6, and this significant difference in the overall plant size gave this huge variation in terms of green biomass quantity, and the same results is also in case of dry biomass quantity, since the ratio of dry/green biomass was not affected by biosolids application.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

According to the findings of this study, biosolids produced by the process of sewage treatment in Al Bireh WWTP is suitable for agricultural utilization as organic amendment, since their maximum heavy metals concentration limits are lower than the permissible limits in three biosolids standards, however, more attention should focus on Ni concentration.

Based on that, biosolids can be regarded as a significant potential alternative for soil amendment, since it can supplement the soil with plant nutrition, in addition to its positive impact on certain physical and chemical properties of soil. Moreover, its valuable economical value in terms of increasing crop productivity, improving soil structure and reduction of applied chemical fertilizers which are widely welcomed. The productivity of Egyptian clover was significantly higher after biosolids application, since all studied growth and development indicators were significantly higher after biosolids application. Biosolids application rate up to 60 tons dry weight for hectares didn’t show any negative influences in terms of plant toxicity, while it provided the highest production. The productivity of Egyptian clover was increased by more than 4 times compared to the control treatment. Accordingly, biosolids can be a valuable source of crop nutrition when it is applied and properly mixed with soil before growing.

Biosolids of Al Bireh WWTP can be utilized after performing natural of artificial drying process, in order to facilitate the handling and soil application processes. It can be also used as fresh biosolids, if the needed facilities for this purpose are available. However, general precautions should be applied to prevent human exposure to biosolids during agricultural handling.

5.2 Recommendations

- It is important to mention that the long-term impact of biosolids applications on agricultural land should be subjected to a further investigation. This investigation has to address the long term impact on HM accumulation in soil and plant tissues, in addition to the impact of biosolids application on different types of soils or other crop species.

- This study is also relevant to other centralized WWTP, which are planned be constructed for the largest communities. The quantities of biosolids will increase by each new constructed plant.
- The future prospects for biosolids utilization in Agriculture must take into consideration the socio-economical contexts for the Palestinian community, in particular the public acceptance for such interventions.
- A further investigation has to address also the short and long term impacts of a large scale biosolids land application practices on soil ecology and microbiology, water resources and other environmental elements. It has to consider also the cost effectiveness compared to other conventional fertilization practices.
- The development of local standards for biosolids classification and utilization, the findings and conclusions of this study could be regarded in complementary with other relevant work. The prospective standards should identify the restrictions on biosolids utilization in agriculture (soil type, crop, climate, water resource vulnerability ...etc).

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ANNEXIES

Annex 1 Mass balance measurement sheets for Heavy metals

Table A-1: Mass balance measurements for B

Sample No	Sampling date	B Conc in Influent (µg/l)	Flow rate (influent) 1000 l/d	Mass in gm/day	B Conc in effluent (µg/l)	Flow rate (effluent) 1000 L/d	Mass out gm/day	Difference gm/day	Ratio of retained mass %
1	15.11.06	302.0	4375	1321.25	178.0	4375	778.750	542.500	41.10
2	30.11.06	158.0	4599	726.642	104.0	4599	478.296	248.346	34.20
3	10.12.06	166.0	4037	670.142	224.0	4037	904.288	-234.146	NA
4	20.12.06	824.0	4406	3630.544	468.0	4406	2062.008	1568.536	43.20
5	03.01.07	224.4	2924	656.1456	239.6	2924	700.590	-44.445	NA
6	15.02.07	532.0	5574	2965.368	182.0	5574	1014.468	1950.900	65.80
7	12.04.07	NA	4552	NA	NA	4552	NA	NA	NA
8	24.04.07	NA	4748	NA	NA	4748	NA	NA	NA
Average		367.73	4401.88	1661.68	232.60	4401.88	989.730	671.950	46.08

Table A-2: Mass balance measurements for Zn

Sample No	Sampling date	Zn Conc in Influent (µg/l)	Flow rate (influent) 1000 l/d	Mass in gm/day	Zn Conc in effluent (µg/l)	Flow rate (effluent) 1000 L/d	Mass out gm/day	Difference gm/day	Ratio of retained mass %
1	15.11.06	958.5	4375.00	4193.44	318.2	4375.00	1392.13	2801.31	66.80
2	30.11.06	812.0	4599.00	3734.39	244.8	4599.00	1125.84	2608.55	69.80
3	10.12.06	540.0	4037.00	2179.98	215.0	4037.00	867.96	1312.03	60.12
4	20.12.06	3496.0	4406.00	15403.38	1480.0	4406.00	6520.88	8882.50	57.70
5	03.01.07	532.0	2924.00	1555.57	228.0	2924.00	666.67	888.90	57.10
6	15.02.07	3212.0	5574.00	17903.69	540.0	5574.00	3009.96	14893.73	83.20
7	12.04.07	448.0	4552.00	2039.30	248.5	4552.00	1131.17	908.12	44.50
8	24.04.07	916.0	4748.00	4349.17	556.0	4748.00	2639.89	1709.28	39.30
Average		1364.31	4401.88	6419.87	478.81	4401.88	2169.31	4250.55	66.20

Table A-3: Mass balance measurements for Cu

Sample No	Sampling date	Cu Conc in Influent (µg/l)	Flow rate (influent) 1000 l/d	Mass in gm/day	Cu Conc in effluent (µg/l)	Flow rate (effluent) 1000 L/d	Mass out gm/day	Difference gm/day	Ratio of retained mass %
1	15.11.06	68.0	4375	297.50	52.4	4375	229.25	68.25	22.90
2	30.11.06	108.0	4599	496.69	55.3	4599	254.32	242.37	48.80
3	10.12.06	59.2	4037	238.99	22.0	4037	88.81	150.18	62.80
4	20.12.06	312.4	4406	1376.43	187.2	4406	824.80	551.63	40.10
5	03.01.07	131.6	2924	384.80	87.2	2924	254.97	129.83	33.70
6	15.02.07	720.0	5574	4013.28	207.6	5574	1157.16	2856.12	71.20
7	12.04.07	214.0	4552	974.13	175.0	4552	796.60	177.53	18.20
8	24.04.07	157.2	4748	746.39	98.4	4748	467.20	279.18	37.40
Average		221.30	4401.88	1066.03	110.64	4401.88	509.14	556.89	52.20

Table A-4: Mass balance measurements Ni

Sample No	Sampling date	Ni Conc in Influent (µg/l)	Flow rate (influent) 1000 l/d	Mass in gm/day	Ni Conc in effluent (µg/l)	Flow rate (effluent) 1000 L/d	Mass out gm/day	Difference gm/day	Ratio of retained mass %
1	15.11.06	70.8	4375	309.75	28.8	4375	126.00	183.75	59.30
2	30.11.06	44.6	4599	205.12	18.1	4599	83.24	121.87	59.40
3	10.12.06	53.6	4037	216.38	14.4	4037	58.13	158.25	73.10
4	20.12.06	98.0	4406	431.79	47.2	4406	207.96	223.82	51.80
5	03.01.07	117.2	2924	342.69	47.6	2924	139.18	203.51	59.40
6	15.02.07	67.6	5574	376.80	33.6	5574	187.29	189.52	50.30
7	12.04.07	104.0	4552	473.41	32.5	4552	147.94	325.47	68.80
8	24.04.07	46.4	4748	220.31	20.5	4748	97.33	122.97	55.80
Average		75.28	4401.88	322.03	28.54	4401.88	123.62	198.41	61.60

Table A-5: Mass balance measurements Cr

Sample No	Sampling date	Cr Conc in Influent (µg/l)	Flow rate (influent) 1000 l/d	Mass in gm/day	Cr Conc in effluent (µg/l)	Flow rate (effluent) 1000 L/d	Mass out gm/day	Difference gm/day	Ratio of retained mass %
1	15.11.06	198.0	4375	866.25	67.0	4375	293.13	573.13	66.20
2	30.11.06	154.2	4599	709.17	46.0	4599	211.55	497.61	70.20
3	10.12.06	108.4	4037	437.61	32.0	4037	129.18	308.43	70.50
4	20.12.06	227.2	4406	1001.04	89.4	4406	393.90	607.15	60.60
5	03.01.07	160.4	2924	469.01	76.8	2924	224.56	244.45	52.10
6	15.02.07	123.2	5574	686.72	56.4	5574	314.37	372.34	54.20
7	12.04.07	221.0	4552	1005.99	51.2	4552	233.06	772.93	76.80
8	24.04.07	113.1	4748	537.00	38.6	4748	183.27	353.73	65.90
Average		163.19	4401.88	714.10	57.18	4401.88	247.88	466.22	65.30

Annex 2: Recorded measurements of plant height and number of leaves at different intervals

Table A.6: Measurements of plant length and number of complete leaves (40 days after planting)

Treatment	Plant length in cm					No of complete leaves per plant				
	R1	**R2**	**R3**	**R4**	**Average**	**R1**	**R2**	**R3**	**R4**	**Average**
Control	7.2	7.5	9.1	8.2	8.000	2.0	2.1	2.0	2.0	2.025
Treatment 1	12.6	14.8	11.8	13.2	13.100	2.5	2.0	2.2	2.2	2.225
Treatment 2	14.4	16.7	13.3	15.5	14.975	2.5	2.8	3.0	2.8	2.775
Treatment 3	17.1	15.2	15.3	17.2	16.200	2.5	3.0	3.2	2.8	2.875

Table A.7 Measurements of plant length and number of complete leaves (50 days after planting)

Treatment	Plant length in cm					No of complete leaves per plant				
	R1	**R2**	**R3**	**R4**	**Average**	**R1**	**R2**	**R3**	**R4**	**Average**
Control	9.7	10	11.8	11.5	10.750	2.2	2.4	2.2	2.2	2.250
Treatment 1	15.7	17.5	14.5	16.2	15.975	2.7	2.4	2.6	2.6	2.575
Treatment 2	18.1	20.2	18.2	19.7	19.050	2.8	3.2	3.2	3.0	3.050
Treatment 3	21.3	20.1	19.8	21.8	20.750	2.8	3.5	3.5	3.0	3.200

Table A.8 Measurements of plant length and number of complete leaves (60 days after planting)

Treatment	Plant length in cm					No of complete leaves per plant				
	R1	**R2**	**R3**	**R4**	**Average**	**R1**	**R2**	**R3**	**R4**	**Average**
Control	12.6	13.1	14.8	14.7	13.800	2.6	2.6	2.5	2.6	2.575
Treatment 1	19.2	21.3	19.2	20.4	20.025	3.2	2.8	2.8	3.0	2.950
Treatment 2	23.1	24.8	22.5	24.1	23.625	3.2	3.5	3.6	3.4	3.425
Treatment 3	26.4	25.2	25.0	26.5	25.775	3.3	3.8	4.0	3.5	3.650

Table A.9 Measurements of plant length and number of complete leaves (70 days after planting)

Treatment	Plant length in cm					No of complete leaves per plant				
	R1	**R2**	**R3**	**R4**	**average**	**R1**	**R2**	**R3**	**R4**	**Average**
Control	16.0	16.4	18.2	18.2	17.200	3.2	3.0	3.0	3.0	3.050
Treatment 1	23.0	25.5	23.6	24.4	24.125	3.7	3.5	3.4	3.6	3.550
Treatment 2	27.1	29.0	26.4	28.4	27.725	3.8	4.0	4.2	3.8	3.950
Treatment 3	30.8	29.2	29.2	30.8	30.000	4.0	4.4	4.4	4.0	4.200

Table A.10 Measurements of plant length and number of complete leaves (80 days after planting)

Treatment	Plant length in cm					No of complete leaves per plant				
	R1	R2	R3	R4	Average	R1	R2	R3	R4	Average
Control	19.8	20.4	22.2	21.8	21.050	3.8	3.6	3.5	3.8	3.675
Treatment 1	27.1	29.4	27.6	28.5	28.150	4.5	4.0	3.8	4.2	4.125
Treatment 2	31.7	33.8	30.8	32.8	32.275	4.5	4.5	4.8	4.4	4.550
Treatment 3	34.8	33.4	33.5	34.8	34.125	4.5	4.8	4.8	4.6	4.675

Table A.11 Measurements of plant length and number of complete leaves (90 days after planting)

Treatment	Plant length in cm					No of complete leaves per plant				
	R1	R2	R3	R4	Average	R1	R2	R3	R4	Average
Control	23.0	23.8	26.0	25.8	24.650	4.5	4.4	4.2	4.6	4.425
Treatment 1	31.7	33.3	31.8	32.8	32.400	5.2	4.6	4.6	5.0	4.850
Treatment 2	36.0	38.2	35.2	37.0	36.600	5.3	5.2	5.5	5.2	5.300
Treatment 3	38.8	37.8	37.6	39.0	38.300	5.2	5.5	5.5	5.2	5.350

Table A.12 Measurements of plant length and number of complete leaves (100 days after planting)

Treatment	Plant length in cm					No of complete leaves per plant				
	R1	R2	R3	R4	Average	R1	R2	R3	R4	Average
Control	27.0	27.6	29.2	29.0	28.200	5.0	5.0	4.8	5.2	5.000
Treatment 1	35.7	37.4	35.8	37.0	36.475	5.8	5.2	5.3	5.5	5.450
Treatment 2	40.5	42.2	39.4	41.2	40.825	5.8	6.0	6.0	5.8	5.900
Treatment 3	42.8	42.0	41.8	44.2	42.700	5.7	6.2	6.0	6.0	5.975

Annex3: Palestinian Standards for effluent reuse

Table A.13 Limit values for effluent reuse (Palestinian Standards, PS 742/2003). PWA, 2003

Parameter (mg/l)	**Discharge to sea (500 m)**	**Recharge**	**Irrigation**					
			Dry fodder	**Fresh fodder**	**Parks and Gardens**	**Industrial and cereal crops**	**Trees and forests**	**Trees**
COD	200	150	200	150	150	200	200	150
TDS	–	1500	1500	1500	1200	1500	1500	1500
NO3-N	25	15			50			
NH4-N	5	10	–	–	50	–	–	–
Organic N	10	10			50			
Cl	–	600	500	500	350	500	500	400
SO4	1000	1000			500			
Na	–	230			200			
Mg	–	150			60			
Ca	–				400			
SAR	–	9	9	9	10	9	9	9
PO4-P	5	15			30			
Cu					0.2			
Fe	2	2			5			
Mn					0.2			
Ni					0.2			
Pb					0.1			
Cd					0.01			
Zn	5	5			2			
Co	1				0.05			
B	2	1			0.7			

ملخص الدراسة

هدفت هذه الدراسة إلى فحص مستويات تراكيز العناصر الثقيلة في الحمأة الناتجة عن عملية المعالجة للمياه العادمة في محطة البيرة . لقد تم من خلال الدراسة فحص أنواع محددة من العناصر الثقيلة والتي قد تتواجد في المياه العادمة الصناعية والمنزلية القادمة للمحطة. لقد هدفت الدراسة بالتحديد إلى فحص مستويات تركيز العناصر الثقيلة في الحمأة لتقييم التأثيرات التي قد تحدثها تلك العناصر إذا ما استخدمت الحماة في تسميد الأراضي الزراعية.

ولتحقيق غرض الدراسة, تم جمع 10 عينات ممثلة للحمأة الناتجة من عملية معالجة المياه العادمة في محطة البيرة خلال فترة ستة أشهر من الخزان الخاص بتكثيف الحمأة في المحطة , ومن ثم تم معالجة العينات وتجهيزها للفحص المخبري بتطبيق الطرق المعيارية لفحص عينات المياه والمياه العادمة باستخدام جهاز (ICP-AES).

تم في البداية تحديد الخصائص الأساسية للحمأة والمتمثلة بالصفات الفيزيوكيميائية (الرقم الهيدروجيني, معامل التوصيل الكهربائي, المواد الصلبة الكلية , المواد الصلبة العالقة , المواد الصلبة العالقة المتطايرة), وقد تم إخضاع العينات فيما بعد للفحص ألمخبري لتحديد مستويات تركيز العناصر الثقيلة (الزنك, النحاس, النيكل, الكروم, الكادميوم, الرصاص والارسينك) بالإضافة إلى عنصر البورون, وذلك باستخدام جهاز (ICP-AES) , من خلال تطبيق الطرق المعيارية لتحليل عينات المياه والمياه العادمة . لقد أثبتت التحاليل التي تم إجراؤها على عينات الحمأة أن الحدود القصوى لتراكيز العناصر الثقيلة وال تي تم قياسها قد بلغت (1150.3, 411.4, 115.7, 232.9, 94, 62.6, 0) ملغم/كغم حمأة جافة على التوالي للعناصر المذكورة , بينما بلغ المستوى الأقصى لتركيز البورون 58.8 ملغم/كغم حمأة جافة. لقد اثبتت التحاليل أن تلك المستويات لم تتجاوز المستويات القصوى المسموحة لتركيز العناصر الثقيلة في الحمأة في كل من المعايير الأمريكية والمعايير الموحدة لدول الاتحاد الأوروبي الخاصة بإضافة الحمأة للأرض الزراعية. وتبين كذلك أن تلك المستويات هي اقل من المستويات القصوى المسموحة الواردة في المعايير الإسرائيلية كذلك باستثناء عنصر النيكل. تشير تلك النتائج إلى أن الحمأة الناتجة عن محطة البيرة لمعالجة المياه العادمة قابلة للاستخدام على الأرض الزراعية من حيث مستويات تراكيز العناصر الثقيلة المفحوصة مع ضرورة تطبيق بعض التقييدات والاحتياطات المتعلقة بطبيعة المحاصيل والأراضي وآي تأثيرات أخرى على البيئة والمصادر الطبيعية.

لقد تم أيضا من خلال الدراسة تحليل ثمانية عينات من المياه العادمة المتدفقة للمحطة والمياه المعالجة الخارجة من المحطة بهدف معرفة تركيز العناصر الثقيلة في كل من التدفقين باستخدام جهاز ICP-AES. لقد بينت التحاليل أن تركيز كل من الزنك, النحاس, النيكل, الكروم, الكادميوم, الرصاص والارسينك في المياه المعالجة كان 1480.0, 207.6, 47.6, 89.4, 0.00, 0.00, و 0.00 ميكرغرام/ليتر على التوالي, وهذه القيم هي اقل من مستويات التركيز لهذه العناصر استنادا إلى المعايير الفلسطينية لإعادة استخدام المياه المعالجة في ري المحاصيل . إضافة الى تلك التحاليل, تم تحديد الكميات المتوقعة من العناصر الثقيلة والتي قد تبقى في الحمأة بعد انتهاء عملية المعالجة . من خلال معرفة تركيز المعادن الثقيلة في المياه العادمة المتدفقة للمحطة والمياه المعالجة الخارجة من المحطة وتطبيق معادلة فرق الكتلة من خلال معرفة معدل حجم التدفق اليومي الداخل والخارج من المحطة في الأوقات التي أخذت فيها العينات.

قامت الدراسة كذلك بإجراء تقييم لقابلية الحمأة المنتجة من محطة البيرة للاستخدام على الأراضي الزراعية من خلال دراسة تأثير إضافة الحماة على إنتاجية المحصول الزراعي في حال أضيفت للتربة وخلطت قبل الزراعة , و لتحقيق ذلك تم إضافة الحمأة المنتجة من محطة البيرة بعد تجفيفها على قطع تجريبية بمساحة 0.25 متر مربع للقطعة بتطبيق أربع معاملات (معدلات إضافة) مختلفة (0, 20, 40, 06 طن للهكتار), بحيث احتوت كل معاملة على 4 مكررات. تم زراعة محصول علفي شائع في القطع التجريبية وهو البرسيم المصري الحولي وذلك لدراسة التأثيرات السلبية أو الايجابية لإضافة الحمأة بالمعدلات المذكورة . ولفحص أية تأثيرات محتملة, تم قياس وتسجيل مؤشرات نمو النباتات خلال فترة نمو المحصول , ونتيجة لذلك , فقد تبين أن إضافة الحمأة

بالمعدلات الثلاثة قد أدى إلى فروق معنوية بالمقارنة مع معاملة الشاهد (بدون إضافة الحماة). وقد وجد أيضا فرقا معنويا بين معدلات نمو وإنتاجية النباتات في المعاملتين الثانية الثالثة 40 و 60 طن للهكتار بالمقارنة مع المعاملة الأولى 20 طن للهكتار, بينما لم يكن هناك أية فروق معنوية بالمقارنة بين المعاملتين 40 و 60 طن للهكتار . إضافة لذلك , لم يلاحظ خلال فترة النمو أية أعراض تشير إلى وجود سمية للعناصر الثقيلة على أي من أجزاء النبات فوق التربة في أي من معاملات التجربة.

إن نتائج هذه الدراسة صحيحة في حالة المحاصيل ذات الدورة القصيرة , إلا أنها لم تتطرق إلى احتمال وجود ملوثات أخرى عضوية وغير عضوية في الحمأة. على أية حال, يجب إجراء فحوص ودراسات إضافية لبحث أية تأثيرات طويلة الأمد لإضافة الحمأة, وكذلك دراسة تأثير الملوثات الأخرى.