QATAR UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

MUNICIPAL BIO-SOLIDS SOIL APPLICATION: SOIL AND PLANT QUALITY AND ENVIRONMENTAL IMPLICATIONS

BY

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ABSTRACT

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Title**:** Municipal Bio-Solids Soil Application: Soil and Plant Quality and Environmental Implications

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Biosolids are utilized worldwide as an organic fertilizer and can enrich barren soils in Qatar, especially if the proper dosage is used.However, it is crucial to study this newly introduced product to the Qatari environment and specify its chemical and physical characteristics along with assessing all the related consequences from using it. Furthermore, it is crucial to know information about biosolid, including its quality, effects on soil and plants as a fertilizer, the ideal and benign application rates, the potential adverse impacts on groundwater, and the possibility to use it as a fertilizer for edible plants. All these are vital to applying the best agricultural practices to use biosolid and to get the best benefits from this recycled material. Studies acknowledge that biosolids have their advantages and disadvantages that should be considered before their usage in soil and the production of both ornamental and edible plants. The main disadvantage is that although biosolids are rich in nutrients, they have heavy metals that are risky pollutants to human health and can lead to cancer and other chronic illnesses due to their harmful effects. Similarly, it can contaminate soils in case of accumulation. Nevertheless, biosolids have been shown to improve crop production significantly in many areas around the world. It is worth noting that Qatar has recently approved the use of biosolids in the production of ornamental plants only. This study was conducted to evaluate the efficiency of biosolid as organic fertilizer in Qatar and address different

concerns associated with its use in the production of food crops. The study attempted to check the effectiveness and efficiency of the biosolid quality via a temporal period of three months for almost one year. Moreover, the study also aimed at checking the efficiency of the recommended dosage of $5kg/m^2$ biosolid by Qatar's government. Different combinations of biosolid were used to review applications rates that are feasible to the soil whereas the development of plants characteristics was good and the contents of nutrients especially nitrogen and phosphorus were much better and the level of pollutants was below the international levels which makes it benign to be used. The study trialed rates of 3Kg, 5kg, and 7Kg of biosolid in the soil to specify the ideal application rate, all planted with *Petunia atkinsiana* plants as indicators. There was also a control treatment with only soil planted with plants. The rates of 5 and 7 kg/m^2 achieved the best plants development for the tested biological parameters, meanwhile, both rates approved rich contents of nutrients along with benign contents of pollutants sufficient to nominate them as the best application rates.

. Another crucial component that was investigated is the potential effect on groundwater and leachability behavior of the biosolids whereas the study discovered insignificant potential effects to contaminate the groundwater by applying these application rates. The biosolid of class A as an organic fertilizer was tried to produce tomato, an edible fruit. Chemical and physical characteristics of the soils and plants are grown using the different application rates of biosolid were discussed in-depth. The study was concluded with recommendations on whether municipal biosolid should be used to produce tomatoes and other edible plants.

DEDICATION

I would like to dedicate this work to my lovely father's soul, my mother, wife and kids, and my country Iraq and my second home country Qatar. My family was paramount in completing this project through their prayers and valuable support. Special dedication also to friends for always being a pillar of support throughout the project.

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CHAPTER 1: LITERATURE REVIEW

1. Introduction

Agriculture is a strategic sector, which plays a vital role for all economies. Its scope is not restricted to food production or food security only, going well beyond into producing many raw materials for other industries. This significant exigency of agriculture requires many basic needs: fertile arable lands, cropping technologies, irrigation infrastructure, and the factors of production such as labor and capital to increase yields (Rajkovic, Smigic, et al. 2017). Since ancient times lost to prehistory, settled communities tried to create different methods to develop various tools and equipment for enhancing agricultural production (Epstein 2017). One of the most significant farming practices is the use of organic fertilizers. The application of trial and errors methods enabled farming cultures worldwide to have a variety of sources for these organic fertilizers, depending on the local resources available (Imai, Cheng et al. 2017).

Today, there are many sources of organic fertilizers actively used in agriculture. There is animal-based biomass, including livestock manure, guano, and other byproducts of the meat processing industries. Urban settlements have made economies of scale in cycling back domestic sewage and septage in the form of sewage sludge, which is now harvested as a sustainable means of waste management by looping back waste as a resource input (Angin, Aslantas et al. 2017), (Rogers 2017) asserts that biomass from plant matter such as compost, peat, and crop residues is another product of the recycling.

This study concerns sewage or septage sludge, otherwise known in Qatar as 'bio-solids', which is the byproduct of wastewater treatment plants. Farmers in the ancient civilizations earlier used sludge as an organic fertilizer. Records indicate that old Iraqis in Mesopotamia have developed a city-scale sanitary system to process human excreta and cycle it back for use in agriculture (Tamburrino 2010). Similarly, the ancient Egyptian 'basin technique' to treat sludge and make it usable for agriculture use is also documented (El Bastawesy and El Ella 2017). This primitive recycling was well-practiced globally as the historical evidence confirms that farmers followed similar practices in China and India during the 18th century (Kumar, Chopra et al. 2017). Human waste was similarly regarded as animal waste, a rich source of nutrients beneficial to crops and has been a backbone of ancient cropping systems in nations such as Mesopotamia, India, and China (Pescod 1992). Due to increasing urbanization, the use of sludge as an organic fertilizer became globally accepted to address the twin objectives of managing waste and generating a useful resource in a loop (Angin, Aslantas et al. 2017).

The treatment of wastewater and its production of sludge as a byproduct have evolved into modern and more sophisticated methods of stringent sanitation standards that are mostly the responsibility of municipal sewerage stations. The treatment stations have become necessary components of both waste disposal and green infrastructure to accommodate the increasing sludge quantities generated by urban populations (Zhang, Hu et al. 2017). The resulting byproducts of treated sewage effluent (TSE) are likewise a useful resource for both urban greenery programs and agricultural production, not to mention the sludge products or bio-solids as indicated earlier (Pescod 1992). In the interest of sanitation, governments impose standards for multiple treatments of wastewater requiring either aerobic or anaerobic digestion, along with physical dissolving and purification, chemical treatment, thickening, dewatering and thermal treatments, and many other efficient, modern techniques to enhance sludge quality

(Kelessidis and Stasinakis 2012). For the year 2017, the sewages were expected to generate forty-six million tons in China for agricultural purposes, 2 million tons in Germany, 7.7 million tons in the United States (Zhang, Hu et al. 2017). According to a follow-up study conducted by (Shen, Wang et al. 2019), sewages generated the targeted tons of products to be used for agricultural purposes.

These indicative quantities will give provide an estimation of millions of tons expected to be generated globally, driven by the high rates of population growth. Therefore, the waste management processes have become a significant world problem for all governments, and they require a solution about how to accommodate the generated quantities adequately as well as to minimize the environmental hazards arising due to such (Wu, Liu et al. 2017). There exist a substantial number of studies to either improve the treatment methods of wastewater and the resulting sludge, the chemical and physical characteristics of these bio-solids, and their application in agriculture (Fytili and Zabaniotou 2008). The findings and better understanding of this research can significantly be used in the cement industry, and the production of biogas for energy (Beloborodko, Romagnoli et al. 2015). Moreover, the main quantities are still conditioned to be used in agricultural-related processes as an organic fertilizer like crop production, lands reclamation, forestry, horticulture, and urban landscaping (Engineering 2017). Despite the significant number of earlier studies on the usage of waste products for agricultural purposes, there are still some questions that have not been addressed. Such items are mostly about the side effects of the waste products, their more significant benefits, and the most effective recycling method to be used (Chaudhary, Dheri et al. 2017).

According to Yilmaz and M. Sönmez (Yilmaz and Sönmez 2017), the sludge product can be defined as the product of wastewater treatment that has received intensive therapy to make it suitable for agriculture use, and it is considered as an excellent organic fertilizer which contains both essential and traces nutritional elements. A study conducted by (Zdruli, Lal et al. 2017) revealed that the bio-solids consists of nutrients like 5.5 % of nitrogen and 2 % of phosphorus in addition to dry solids, organic matters, trace elements like zinc and iron, as well as some undesirable heavy metals such as lead and copper. The use of bio-solids as an agricultural fertilizer is regarded to be the most sustainable practice as the material is 100% recycled (Zdruli, Lal et al. 2017). Furthermore, studies conducted by (Guimarães, Lamandé et al. 2017) also point out that sludge significantly enhances soil properties by releasing fertilizer slowly; hence ensuring the availability of nutrients during different stages of plant growth. Likewise, it promotes the growth of beneficial soil micro-organisms, soil structure, and aeration (Hall, 2017).

Despite these compelling advantages, there are also disadvantages in using sludge, primarily owing to undesirable heavy metals that contaminate sludge (Rao, Thomas et al. 2017). Similarly, open and repeated applications with sludge could contaminate the groundwater with nutrients or even pathogens if the thermal treatment was not appropriately arranged (Dizman, Görür et al. 2017). There is also is the cultural constraint of the perceived suitability of sludge in the Middle East owing to cultural taboos on how waste is regarded with its pathogenic content, even if treated (Hall, 2016). The resulting sludge quality, end-product applications and targeted soil textures vary from one country to another due to different methods of waste treatment. These differences motivate universities and research centers to keep researching and to set their manuals and guidance documents (Authority, Q.S.A.-P.W., 2018). These specifications are about the best benign methods to use bio-solids in agriculture along with specifying products specifications, application rates and other husbandry practices to minimize the possible negative environmental impacts that might appear in using sludge.

In compliance with the above and by owing to necessity, Qatar has constructed and commissioned a Thermal Dryer Plant at Doha North STW (DN STW). This plant is capable of producing Class A [i.e. pelletized sludge suitable for unrestricted uses], Class B [i.e. sludge cake] and TSE water (Engineering 2017). The authorities have approved the use of Class A as an organic fertilizer for ornamental plants and landscaping purposes only (Public Work Authority 2017). The estimated quantities to be generated daily are almost 100 tons, where 80 tons are used to produce Class A, and 20 tons for Class B. Government authorities in Qatar have specified the potential practices in using these quantities for landscape construction, following the move to extend Qatar's green infrastructure the significant cities. This has also been mostly possible due to ample supplies of TSE made available for landscape irrigation. Year-on-year operations and maintenance [O+M] of these green assets to international practice incorporate or encourage the use of sludge in the public realm [e.g. public parks, open spaces and gardens, streetscape planting (Engineering 2017). Qatari authorities are strategically aiming to enrich the barren soils in the country with these recycled bio-solids (Babikir 1984). This hypothesis is based on a geological and geographical soils survey which identified the Qatari lands over the country as mostly lithosol. They are approximately shallow, with an identical depth of around 10-30cms only with few sandy loam pockets known as 'rawdha' (Babikir 1984). Such infertile, calcareous sandy loams are surfaced with rock debris whereas this blanket of fragmented rocks is settled above limestone bedrock. Furthermore, there are few lands with high salinity, commonly known as Sabkha soil, and it is not suitable for cultivation (Al-Thani and Yasseen 2017). FAO studies estimated 2.5 % of the total land of Qatar as ideal for agricultural purposes which is around 28,000 hectares planted mostly with annual crops like vegetables or green rations (Babikir, 1984).

Sludge, as a new introductory product to the Qatari environment, deserves to be studied better to help to set the national policy to turn it to a beneficial outcome and to minimize any adverse environmental impacts. The scientific methodology will help to assess the quality of produced sludge in terms of its physical and chemical characteristics. Meanwhile, it has become a necessity to evaluate the nutritional value of such products before applying them to landscaping sites that consist of various types of plants categories of palms, trees, shrubs, ground covers, and grasses. The study is not limited to the product itself, as it must set a stringent procedure to work following a holistic view and integrated manner for designing a robust model concerning the exact application rates based on soil types and plants' actual needs. This scientific approach will include studying the impacts on the groundwater and expected leachates from a land fertilized rich nutrients and heavy metals pollutants at the same time. In a nutshell, it became a necessary demand to conduct an applicable study that helps in organizing the use of bio-solids, bearing in mind that similar products are a two-sided sword, and they assist in setting a national policy that preserves the valuable lands and water resources from reaching the limits (Wolf, Baretta et al. 2017).

1. Literatures Review

Organic fertilizers are essential in improving soil fertility. The ancient communities used organic fertilizers in boosting agricultural yields, just as it is nowadays in meeting food security demands brought about by population increase (Chaudhary, Dheri et al. 2017). The importance of using organic matter taken from various sources to enrich soils has enabled farming to take off due to the perceptible substantial, increased yields. Organic matter betters soil properties in ways such as improving soil structure, drawing helpful microorganisms and amplifying the water holding capacity, and many more. Thus, it is crucial to reclaim and restore lands that have become marginally productive (Wu, Liu et al. 2017). Throughout agricultural history, farming societies had been well aware of the significance of organic matter. Its helpful impacts have been known to transform degraded soils by boosting aeration (Verma, Maurya et al. 2017), minimizing the risks of erosion by stabilizing soil composition (Bertol, Luciano et al. 2017) while promoting biotic activities necessary in producing minerals and further nutrients accessible for plant uptake(Li, Tao et al. 2017).

With the scientific advancements, people nowadays have a better comprehension of the place and function of organic matter, as a variety of ordinary organic fertilizers, in food production (Cubins, Lewins et al. 2017). Understanding its constituents and the method of the act in the loams, as well as plant uptake, is crucial in promoting better usage (Shahbaz, Kuzyakov et al. 2017). Even though the use of organic fertilizers has the advantage of increasing crop production, they potentially affect soil fertility and deplete soil nutrients when inappropriately practiced (Shahbaz, Kuzyakov et al. 2017).

(Fernández-Martínez, Vicca et al. 2017) asserts that farmers have started to raise essential questions on the nature and content of organic fertilizers due to the potential harm. To this as well as many more issues, science has tipped to several solutions on how fertilizer functions: at the beginning of planting, as a rapid, complete source of plants' nutrients; and all through the crop period, as a basis of providing nutrients on a usual, sustained source to gratify the requirements of enlarged crop production (Yilmaz and Sönmez 2017).

The first description of sludge as semi-solids or solids products from the handling of sewerage location seems to be partial and insufficient. What should be understood are the diverse types of fertilizers and their matching works, and this has led to an exceptional field of study with many findings of both artificial and organic fertilizers (Guimarães, Lamandé et al. 2017). It is essential to note that the word 'organic' is frequently understood as an identification of natural (Cooper 2017), which is not completely exact given dissimilar management processes for organic matter (Dai, Huang et al. 2017). It can be satisfactory for contrast with artificial fertilizer (Tambone and Adani 2017).

4.1. Macro and Micro-Nutrients

Researchers categorized two major groups of nutrients on basis of the requirements of these constituents by a plant (Cooper 2017). The primaries are the macronutrients required by plants in larger quantities like (nitrogen, phosphorous, potassium, sulfur, magnesium, and calcium (Shaheen, Khan et al. 2017). Their relevance rates are frequently computed by pounds per hectare [kilogram per hectare (Cubins, Lewins et al. 2017). The second is the micronutrients (Nabavi, Daglia et al. 2017), which are needed by plants in lesser or trace amounts (less than one lb. per acre). For instance, elements like boron, molybdenum, copper, chlorine, zinc, iron, and manganese are micronutrients (Nathan 2017). The want for utilizing these two groups of nutrients differs in respect to the desired intention: whether for controlling the PH of soil (Wang, Zhang et al. 2017), or increasing crop yields (Fernández-Martínez, Vicca et al. 2017), or to maintaining green infrastructure (Hiemstra, Saaroni et al. 2017). Sometimes, the need for targeted nutrient application may be for increased flowering (Sletvold, Tye et al. 2017).

4.2. Organic Fertilizers

As a rule, organic fertilizers are one of the critical and best strategies to fortify soil structure (Rahman, Zhu et al. 2017). They enhance its efficiency and nutritional abilities (Moharana, Sharma et al. 2017), being generally non – poisonous or benign (Wolf, Baretta et al. 2017). The raw materials as compostable biomass, (for example, horticultural ranch squander, yard litter from scene upkeep) are frequently promptly accessible for creating organic fertilizers (Ghimire, Lamichhane et al. 2017). Likewise, urban populace development makes it conceivable to add to crude materials for organic fertilizers with economies of scale. Residential sewage slime created by squander treatment plants is processed into manure (Lau, Li et al. 2017), which guarantees an assortment of hotspots for producing natural compost (Urbaniak, Wyrwicka et al. 2017). The advantage of using these sources is that now and again, it tends to be less expensive to create with less capital venture (Capodaglio and Callegari 2017), as it reasonably cycles back waste into a reusable asset. Besides, it's less expensive from multiple points of view as it requires reused material (Ren, Liang et al. 2017). Another advantage is that, unlike the chemical fertilizers, it allows an increasingly slow time of supplements to be discharged for plant take-up, in this manner lessening waste when full arrival of supplements drain out into the soil (Foereid 2017).

1.3.Types of Organic Fertilizers

There are diverse sources for making organic fertilizers, including livestock manure (Lai, Arca et al. 2017), mulch (Awopegba, Oladele et al. 2017), and other plant-derived residues from biomass (Lubbers, Pulleman et al. 2017), processed excreta from humans, in sludge form (Winker, Vinnerås et al. 2009). Of all the sources for generating organic fertilizers, treated sludge is the subject of this review, and it is discussed in the proceeding part. It is needed first to know what 'sludge' is, how it is produced, and its history of use to give a proper context of sludge, (Senesi 1989). Sewage treatment plants process domestic wastewater that results in two useful byproducts: one is treated sewage effluent [TSE] and sewage sludge (Xu, Li et al. 2017). TSE is increasingly cycled back for use in public works landscaping that serves as the backbone of urban greenery programs. The other is sludge which is also cycled back for agriculture or urban green infrastructure.

1.4. Sludge as a Byproducts

Sludge is the byproduct of gathered solids or semi-solids from sewage waste treatment plants (Alleman and Berman 1984). Andres (Andres 1999) describes sludge as the byproduct of wastewater management that has been subjected to thorough management to make it appropriate for use in landscaping or agriculture as an organic fertilizer and soil conditioner. The rest of the deposits are additionally treated and ordered into class-A, which is the dried-out items framed for the most part into pellets (pelletized slop) (Watanabe and Tanaka 1999). Or then again class B, known as slime cake, is evaporated to a particular degree of thermal treatment and comes next in preference for use as natural manure (Pepper, Zerzghi et al. 2008).

History

1.4.1. Ancient Practices

Literature has diverse stimulating stories about the application of domestic ravage in ancient times. As untimely as 4000 BCE in Iraq (Mesopotamia), water technology was not only for irrigation but, also pioneered by Iraqis in sanitary engineering (Law, Herzke et al. 2008). Many urban street designs had connections of waste sewer and storm water drainage systems (Rao, Thomas et al. 2017). Babylonians were recognized for their pipe manufacturing abilities. They had the know-how to manufacture pipes from various materials like terracotta, copper, and lead (Gray 1940). Correspondingly, the technique of (basin irrigation) water administration utilized in ancient Egypt ensured an adequate treatment for the wastewater via percolation process, where the soil bacteria naturally digested the residues before falling into or entering water channels and streams (El Bastawesy and El Ella 2017).

In addition to these ancient civilizations, records reveal facts of a similar concept applied in Rome about 500 BCE where streets had a system of supplying pure water to households and another system to drain the excreta of the private and public toilets in homes of wealthy people (Beagon 1992). In this way, the reusing of human excreta isn't new. Sludge had been utilized for crops creation for quite a long time in different areas of Asia (Rockefeller 1998), while it had confined use in Europe until the nineteenth century (Andres 1999). The utilization of sludge in farming exercises is generally viewed as the most maintainable option (Winkler, Meunier et al. 2017). (Ren, Liang et al. 2017) note that “it is the most important and well-established outlet for sludge in many countries, especially when farmers earlier realized that sludge supplies nutrients, organic matters and provides a partial or full replacement for animal manure and fertilizer. "

1.4.2. History of Use in Europe

In the beginning, sludge was very distinguishable and commonly practiced in Asia, in contrast to Europe (Law, Herzke et al. 2008). In Western Europe, for example, the use of sludge in agriculture varies from 10% of the total produced quantities in Sweden to 70% in Spain (Masciandaro, Peruzzi et al. 2017). But it was reduced 50% from 1995-2009 due to restrictions against landfilling. Research shows that there is a growing movement of production and usage of sludge in eastern and central of Europe, especially with the development of wastewater treatment plant methods (Kelessidis and Stasinakis 2012). Unfortunately, there is not enough empirical data on the use of sludge for agricultural purposes that have been formally recorded. However, it is confirmed that the disposal methods mainly involve the open-dumping of these excreta into farms and backyards of the cities or even in rivers, which are interacting indirectly with the rural environment (Bianchini, Bonfiglioli et al. 2016).

1.4.3. History of Use in the Developing World

Till recently, the trend of using wastewater or sludge is still increasing in the world, especially in Asia and Africa owing, to the attractiveness of recycling. For example, it is known that the generated mass of sewage sludge in China will reach 46 million tons per year (Fu, Huang et al. 2015). Furthermore, there are still many areas where farmers are using these products for the production of food, as had been practiced in ancient China. Its use in growing cereal crops seems to be of no severe sanitation concern, as cooking sterilizes out any pathogens or microorganisms (Eichenseher 2010).

1.5. Modern Use in Europe

The world wanted to deal with this problem and expanded technologies to handle sludge and realize benefits. Hence, it turned out to be prevalent to use wastewater management plants for agricultural or landscaping rationale as a noteworthy expansion realized in management technologies (Sewage and Sludge 1998). The practice also minimizes toxic waste and satisfies hygiene safety. The use of sludge byproducts in Europe's mature industry had long been accepted socially, with communities served by sewage treatment plants in Denmark, Sweden, Netherland, and Luxembourg (Sewage and Sludge 1998). The EU's population generates 420 million tons of waste, and fifty tons are only recovered potentially for energy. The remaining quantities are used to produce organic fertilizers or as organic matter (Plan 2011).

Using sludge as a conditioner to advance soil because of its nutrient contents [e.g. nitrogen, potassium, and phosphorus] in gardens and parks has turned out to be very common (Pescod 1992). Notable examples include the Stockley Park in London where a 100-hectare derelict site was converted to an award-winning golf course. Nevertheless, the Business Park had its soil formulated in-situ from suitably textured mineral material found onsite and conditioned with 100,000 m^3 of air-dried sludge (Panter and Hawkins 1991). Approximately 62% of the total quantities of sludge in the UK are nowadays recycled to agricultural land, but laws have restricted the use of sludge as fertilizer. Even with these legislations, it is still more about organizing the process rather than refraining from using it (Smith, Fowler et al. 2009).

1.6. Present Use in the Middle East

In the Middle East, for example, the large-scale use of sludge on land is not well established. Social resistance may partly explain this but is more related to often poor quality sludge and sludge producers who find landfill disposal a cheaper and more accessible outlet to manage (Hall, 2017). In Abu Dhabi [UAE], solid waste biomass and sludge have been composted together, and their Parks and Gardens Department widely uses the product for landscape maintenance (Katkhuda). Nevertheless, farmers tend to be cautious about the initial usage where there is a limited experience. However, there are examples of highly successful and widespread use of sludge such as in Egypt, where the practical demonstration of the value of sludge rapidly overcame any social resistance and unlocked a sizeable latent demand turning a disposal activity into a revenue stream (Lowman, McDonald et al. 2013).

In general, it could be positively stated that there are several types of sludge (Public Work Authority 2017) First, there is Class A sludge, which is the dry pelletized sludge, while the product is dry and granular, making it easy to apply and mix with soil. It has no offensive odor, and due to pasteurized heat treatment, it is safe to handle as a potential health risk is minimized. Secondly, there is Class B sludge, which is widely known as Sludge Cake. It can only be used on permitted land. Its use is controlled; despite being treated thermally in a different process that doesn’t include a complete drying or further chemical treatments like Class A. Thirdly, there is Class C, which is a sort of class B but with a different rate of thermal treatment or the time of processing. Additionally, there is Class D, which is the raw sludge after the physical dissolving of water with a simple dewatering treatment. It is rarely used nowadays for landfills only but not for agricultural purposes.

1.7. Chemical composition and structure of sludge

In general, sludge is similar in many respects to animal manure in nutrient composition, including essential trace elements. Sludge contains typically about 5.5% nitrogen and 2% phosphorus on a dry matter basis. These nutrients are necessary for plants. In the meantime, the regulations and caveats about the exploitation of sludge emerged because of its pathogen and intense metal content, predominantly weighty metals that elevate the food chain (Hall, 2017), and are poisonous at several concentrations (Carrondo, Lester et al. 1978). The existence of these weighty metals fundamentally is as indicator of the degree of contagion and correspondingly, the organic matter substance is a pointer of the extent of sludge stabilization as a functional value indicator for the sludge consumer (Jupp, Fowler et al. 2017).

1.8. Sludge Components

Dry solids, organic matter, nutrients and the undesirable and potentially harmful heavy metals are the significant components of sludge (Ashrafzadeh, Lehto et al. 2017). A better understanding of these risky components permits advanced management, mitigation, and the cost of using sludge, as stipulated in many guidance manuals issued by authorities. In these manuals, heavy metals [e.g., zinc (Zn) copper (Cu), mercury (Hg), lead (Pb), cadmium (Cd), nickel (Ni), arsenic (As), thallium (Tl), and chromium (Cr)] are examined with apprehension for the risks they facade (Ashrafzadeh, Lehto et al. 2017). There is an extended list of heavy metals, but the focuses of this paper are on those mentioned. The implication of these metallic chemical aspects emerges from numerous facts that can be abridged as follows: (i) several of them are required in trace concentrations for the development of plants like zinc for example (Samreen, Shah et al. 2013); (ii) these do not naturally degrade, and they elevate the food chain (Falih 1997); (iii) many of these metals are incredibly poisonous, and this toxicity ranges from being classified as exceedingly noxious (one or two micrograms) to a small toxicity constituent like bismuth (Påhlsson 1989); (iv) these are heavy due to its high density and atomic mass (Calace, Nardi et al. 2017); (v) it causes severe hazards to both human and animal health because of its accumulative impacts in poisonous amounts throughout exposure to such components (Rao, Thomas et al. 2017); and (vi) the effect mechanism of such elements is manifested by accumulation in the bodies' soft tissues, which will lead to severe damages of the central nervous system and the cardiovascular (Rao, Thomas et al. 2017).

The incidence of these harmful inorganic chemical collections in the sludge directed to the setting of numerous manuals based on the absorptions of such constituents in the soil prior to relevance and the produced bio-solids as well. The manuals are arranged to specify the exact limits of occurrence in the treated soil with a calculation for cumulative additions of heavy metals to land, based on sludge quality and rate of application. Based on these differing concentrations from one kind of soil texture to another, many nations have set restrictions allowed in the sludge. Tables 1-3 specify the permitted limits for each element (Public Work Authority 2017).

Table 1: Comparison of Loading and Soil Quality Limits in USEPA 40 CFR Part 503 and EC Directive 86/278/EEC (Hall, 2016).

	Loading limit (kg/ha per y)		**Soil concentration (mg/kg ds)**	
Heavy metal	**USEPA**	**EC(1)**	**USEPA(2)**	**EC**
Zinc	140	30	1,460	150 to 450(3)
Copper	75	12	770	50 to 210(3)
Nickel	21	3	230	30 to 112(3)
Cadmium	1.9	0.15	20(4)	1-3

Lead	15(4)	15	180(4)	50-300
Mercury	0.85	0.1	8.5(4)	1-1.5
Chromium	150	-	1,530	-
Molybdenum	0.9(5)	-	9.5(5)	-
Selenium	5	-	50(4)	-
Arsenic	2	-	21(4)	-

Note: (1) The loading rate is averaged over ten years in the EU, (2) Calculated values as Part 503 does not place soil restrictions for PTEs, (3) Higher costs are allowed for calcareous soils having >5% calcium carbonate, (4) To guard children who consume 0.2 g daily, sludge used in farms for the first five years of life, (5) This has been reserved for reassessment.

Table 2: Heavy Metal Limit Values in Sludge and Soil (GCC) (Public Works Authority 2017)

	Maximum Limit Concentration (mg/kg)	
Element	**Sludge**	**Soil**
Zinc	500	300
Copper	400	100
Nickel	200	50
Cadmium	20	2
Lead	300	30
Mercury	10	1

Element	Maximum Limit Concentration (mg/kg)	
	Sludge	**Soil**
Chromium	300	150
Arsenic	10	4
Selenium	50	5
Molybdenum	20	3

Table 3: Comparison of Regional Sludge Quality Standards (mg/kg ds)(Public Works Authority 2017)

Heavy metal	GCC	Abu Dhabi	Egypt	Palestine	Jordan			Syria			
					Class 1	Class 2	Class 3	Class A	Class B	Class C	Class D
Zn	500	3000	2800	2,500	3800	4000	7500	200	700	2,500	2,800
Cu	400	1000	1500	1,000	1500	3000	4300	100	375	1,500	1,500
Ni	200	200	420	200	300	400	420	60	125	270	300
Cd	20	20	39	10	40	40	85	3	5	20	32
Pb	300	800	300	300	300	840	840	150	150	300	400
Hg	10	10	17	5	17	57	57	1	4	15	19
Cr	300	1000	1200	500	900	900	3000	100	250	500	600
As	10	10	41	2	41	75	75	20	20	20	30
Se	50	50	36	30	100	100	100	5	8	50	90
Mo	20	20	18	10	75	75	75	-	-	-	-

GCC – Fertilizer Law 2006

Abu Dhabi – Ministry of Agriculture and Fisheries Ministerial Decree 214/2004 Egypt

– Minister of Housing, Utilities and Urban Communities Decree 214/1997 Palestine – draft standard, 2005

Jordan – JS 1145/2006. (Class 1 – agriculture; Class 2 – soil improvement; Class 3 – landfill)

Syria – SASMO 2665/2002. (Class A – unrestricted; Class B – except gardens; Class C – except parks; Class D – except agriculture).

1.9. Using sludge as an organic fertilizer

The utilization of sludge in agriculture is extensively recognized as the most sustainable sludge supervisory option. Furthermore, sludge is the most significant and entrenched opening for sludge in many countries (Ren, Liang et al. 2017). Sludge supplies nutrients and organic matter and provides a partial or full replacement for animal manure and fertilizer (Kacprzak, Neczaj et al. 2017). The appliance rate of bio-solids is typically resolved by the nutrient needs of the produce in the range of 5 - 10 TDS/ha. Habitual appliances of sludge steadily advance the organic matter position of soil with benefits to water holding capacity and soil texture. Still, for unproductive lands, such as those in Qatar, for example, advanced rates may be essential to realize untimely and sustained developments to physical soil states (Public Works Authority 2017).

Several studies and risk evaluations conducted over the last forty years or so kept stressing that scientific and well-organized utilization of sludge, which bouts with commended rules and regulations to thwart the ecological risks and damage on human health. As described previously, sludge uses on land is highly regulated, more so than any other agricultural resource (Alvarenga, Palma et al. 2017).

Large-scale use of sludge on land is not well established in the Middle East. Social opposition and cultural views partially clarify this, but are more related to often poor sludge quality and sludge manufacturers who discover landfill clearance as cheaper and more reachable channel to administer. However, there are examples of highly successful and widespread use of sludge in nations such as Egypt where the practical demonstration of the value of sludge rapidly overcame any social resistance and unlocked a sizeable latent demand turning a disposal activity into a revenue stream (Kacprzak, Neczaj et al. 2017).

Nonetheless, concerns may be lifted by the public over the suitability of food grown on sludge-treated soils, and in various nations, the application of sludge on land has become hard due to the unfavorable insights of food retailers (Public Work Authority 2017).

Such issues can be addressed frequently by providing suitable information, advertising activities, and thorough dialogue. For example, in the UK, the British Retail Consortium (BRC) questioned the acceptability of sludge use on land and in negotiations between BRC. The sludge producers and regulators had to go beyond scientific assessment and regulatory requirements to redefine good practice in a form that the public was content with it. The result was the ‘Safe Sludge Matrix which has strengthened the sludge use on land in the UK (Rajkovic, Smigic et al. 2017).

It is significant to know that the recognition of sludge by farmers is deliberate. As a consequence, demand can be susceptible to speedy changes in the farmers’ attitudes to sludge (Epstein 2017). Demand for sludge will also be variable due to the seasonality of crop production. Similarly, studying the farmer's needs is crucial regulation of supplying and providing a high-quality product and remains essential for creating and sustaining the product to a land program. Notably, the targeted markets have many alternative fertilizers with limited capacity (Public Work Authority 2017).

In spite of the weighty metals in the sewage sludge, the division of such resources in the farming land should suit the rules and conditions of utilizing sludge in crop growing. Such rules can include arranging for the appropriate sludge tests and ensuring that metals absorption remains within the allowed levels and that the treated soil has a high pH (more than 5) (Haroun, Idris et al. 2009). Similarly, the methods of treatment are also one of the significant parameters as the sludge characteristically has high water and organic content (Carrondo, Lester et al. 1978). Hence, the process of solidifying and dewatering preserve precise importance as it influences the appropriateness and performance of the entire handling system (Demirbas, Edris et al. 2017).

Sludge is conditioned before starting the processes of thickening and dewatering. Two types of conditioning chemicals are applied to improve the treatability of the sludge: (i) mineral chemicals like iron salts and lime; and (ii) organic chemicals like coagulants and flocculants. The most used type of flocculants processed is cationic (Watanabe and Tanaka 1999).

Sludge can be usefully used for every crop, but as an additional precaution, sludge should not be applied to vegetable crops or fruits, which are consumed raw (Andres 1999). The research conducted by Hall (2017) disclosed some common guidelines on the usage of sludge as an organic fertilizer. The findings can be abbreviated as follows: (i) there is no inconsistency with good landscaping or agricultural; (ii) the long-term feasibility of farming activities and landscaping objectives can be upheld; (iii) public pollution and nuisance will be evaded; and (iv) the health of people, animals or plants must not be put at risk. This limitation fundamentally incorporates numerous subtleties which change from one nation to another, with an understanding of all the strategies and tests required to guarantee that the treatment is adequate to make the created sludge beneficial. For additional elaboration about this point, models from various determinations are referenced: (I) limit esteems for pathogens and parasites are not set in Europe as this isn't viewed as fundamental dependence on the supposition that if a treatment procedure meets the right procedure conditions, the decrease in pathogen numbers can prognosticate. The adoption of restrictions on use further manages the potential transmission of disease. For instance: crops eaten uncooked cannot grow for ten months after application and animals cannot graze pasture for three weeks after application (Kacprzak, Neczaj et al. 2017); (ii) in Asia, only strategic crops such corn, wheat, and barley, are advocated to be fertilized by sludge. The reason behind that is because these plants have stems, and the consumable parts are not in connection with the fertilized soil, and the second point is that these kinds of crops are eaten when cooked (Lin, Nguyen et al. 2017); (iii) in the US the EC restricts the order rather than the heavy metal values for sludge quality and additional rates (yearly loading boundary). The adopted specifications are derived from extensive risk assessment, and this has resulted in generally higher values than those proposed (Lowman et al., 2013). Nevertheless, some USEPA limits are lower than the corresponding EC limits. For instance led, in response to the risk analysis of unrestricted use (i.e., potential exposure of children by eating sludge-treated garden soil); (iv) in the GCC states copper and zinc are the pinnacle priorities limitations of the heavy metals due to the soaring percentage of these components in the soil (Association 2003); and (v) in the Qatari specifications, only thermal treated pelletized sludge of class A is permitted to apply for fertilizing decorative plants and not any other product (Authority 2018). Sludge does not replace all of the fertilizer requirements of most crops with the possible exception of legume crops. So, additional fertilizer may need to be applied, but, the amounts required will be reduced, hence saving money. The steps to calculating the amount of fertilizer involve too many interacted factors like the contents of nutrients in the soil before application, and the contents of nutrients in the sludge, and the type of crops in the land. Generally, the manuals of utilizing sludge as a natural fertilizer set a few general strides to be taken base on the above investigation and the kind of yields. They can be truncated as follows (Public Works Authority 2017): (I) the assessment of the sludge given by makers will incorporate all elements of nitrogen and phosphorus. It ought to be introduced on basis of dry and fresh solids, considering the moisture of the sludge as conveyed; (ii) the accessible supplements in the sludge ought to be determined; (iii) phosphorus needs of the crop ought to be partitioned by the measure of accessible Phosphorus in the sludge to give the application pace of the sludge; (iv) sludge applied in light of present conditions will at that point give the entirety of the nitrogen and phosphorus needs of the harvest; (v) along these same lines of use, ascertain the measure of accessible nitrogen that would be applied by the sludge; and (vi) take away this sum from the aggregate sum of nitrogen fertilizer required by the yield. The outcome will be the measure of extra nitrogen manure that ought to be applied. In general, this will avoid the need to apply compound fertilizer (this is the most expensive type of fertilizer), and a reduced amount of urea will be required. With the regular application of sludge, the fertility of the soil will increase, which may allow fertilizer rates to be reduced further depending on the yields achieved (Verma, Maurya, et al. 2017).

All in all, it can be expressed that the best possible utilization of sludge according to a logical rule and by adhering to all the standards and guidelines would essentially improve the soil properties and help to deliver astounding yields, which speak to an amiable and great reused substitution for the organic compost.

1.10. Advantages and disadvantages of using sludge

One of the significant benefits of thermally dried sludge is its consistent quality (physically, chemically, and microbiologically). It is crucial to explicitly clarify that the use of sludge might be a two-sided sword. There are lots of advantages gained from this recycled material if ever the production and application have been made according to a very restricted management policy which will lead to achieving fruitful results without any harmful effects on the environment, human, animals, and plants health (Nartey, Amoah et al. 2017). Meanwhile, working blindly without having a clear policy will create an environmental disturbance and results could be worse, in case there was a significant defect in one of the essential stages of treatment or control of the application. It means that the sludge application should be run by a substantial government authority (Yue, Cui et al. 2017). This authority will make sure that the users are following the scientific procedure as well as supporting the established standards to avoid environmental catastrophes (Nartey, Amoah et al. 2017). Hence, many countries base national standards for sludge use on land on those approved in the US (Rule 503) or in the European Union (under Directive 86/278/EEC). The philosophies behind the controls adopted in these two regions are often considered to represent the extremes of approaches. The US follows a risk assessment approach to derive scientifically based environmental and health quality standards, while in Europe, the more prudent plan is considered. That has become progressively more restrictive as public awareness, and perception of specific issues has increased (Du and Li 2017). it is needed to specify the most common advantages and disadvantages of using the sludge to cover this essential part of the topic.

1.11. Advantages of sludge

The benefits linked with sludge can be summarized as follows: (i) it is a low-cost fertilizer that serves as a soil conditioner; (ii) it saves on costs by lessening the required amounts of phosphate and nitrogen fertilizers; (iii) it increases the organic content of soil by bettering soil for crop production; (iv) It is rich in micro-elements such as Cu, Zn, Mn and Fe; (v) it is free from weed; (vi) it releases nutrients slowly hence improving the plant growth by availing nutrients during different stages of plant growth; (vii) its residual benefits subsequent crops; (viii) It has a low cost of application, especially the Class A, that makes it easier for pellets to be used and mixed with soil; (ix); It meets the central specs of sustainability as it can be recycled up to 100%; (x) It is almost free from any natural agents such as fungi, bacteria and insects as the present methods of thermal treatment and dewatering are followed globally, hence enhancing adequate quality of sterilization and comes up with benign product used in accordance to the international standards; (xi) It is free from odor, this is for both class A and B, hence reducing any annoyance for the public (Djafari, Semcha et al. 2017); (xii) production of sludge through the modern technology avoids serious environmental problems and complicated issues that otherwise could not be controlled if traditional methods such as the burning and landfill are used (Wei, Zhou et al. 2017); (xiii) The use of sludge as a soil conditioner or an organic fertilizer can significantly improve the environmental conditions as it can minimize the persistent wandering of peat bogs by organizations to make peat moss; (xiv) Sludge can be an outstanding binder to steady and enhance soil properties with its organic elements (Djafari, Semcha et al. 2017) ; (xv) sludge combustion as a component of replacement fuel is an industrial process that is energy-intensive, especially in cement production, and can implementable in appropriate industries near the STW; and (xvi) it adds a significant decrease in net Co2 emissions which has a growing economic value in states that have to follow the Kyoto protocol. Additionally, sludge has no disposal residual as the sludge ash is integrated into the product without any harm to its public technical performance (Djafari, Semcha et al. 2017).

1.11.1. Disadvantages of Sludge

The usage of sludge has various detriments which can be summarized as follows: (i) the production method of sludge is not usually flexible or firm, particularly for the older sewerage systems. This factor has the potential of affecting the process by augmenting the volume of effluent out of the station's capability. Furthermore, this can lead to uninspired disparities in the sewage character, and consequently, end up with the low quality of treated sludge (Djafari, Semcha et al. 2017). The main issue behind this problem is that the design of the sewerage stations is not arranged to handle the capacity of actual quantities produced daily or the treatment system itself is not sufficiently manufactured to accommodate such volumes, while sometimes the lack of the proper maintenance will create such problem public (Djafari, Semcha et al. 2017); ((ii) infrastructures of the contemporary sewerage stations together with appropriate operations are costly and demand substantial financial resources (Hall, 2016); (iii) the clearance of the generated sludge is at times required in large volumes; (iv) the process of production is affected easily by some industrial sags, and this is the primary reason as to why the international standards emphasized on managing the small manufacturing projects. The drained waste administration might be weak and can be a cause of heavy metal contamination such as copper or lead, which can significantly affect the quality of sludge; (v) Educated and skilled personnel is needed to oversee all the stages of production. Individuals working in this field must have adequate responsiveness about the essentiality of treatment methods and the environmental risks that might transpire due to inappropriate management of public sludge (Djafari, Semcha et al. 2017).

Moreover, the modern methods of treatment and facilities go well beyond just being skilled as it requires an engineering degree and technicians ran by experts to operate these stations and biologists to do the sampling lab tests to wind up with a good quality of treated sludge (Hall, 2016); (vi) heavy metal accumulation due to replicated sludge applications can create environmental problems, especially when there is no calculation or analysis of soil contents of these poisonous inorganic compounds. Furthermore, it poses health risks to humans, plants, and animals as the metallic components cannot be easily destroyed, hence transferring them through the food chain (Dotaniya, Meena et al. 2017). Inappropriate thermal treatment can further pose a problem as the incidence of diverse types of pathogenic agents is considerably expected in the raw materials of sludge. The production process eradicates the pathogens through anaerobic and aerobic digestion means. At the same time, other sorts of microorganisms function to break down the biological materials that can be degraded to more balanced substances (Trivedi, Singh et al. 2017). Failure to accomplish this process efficiently will make the produced bio-solids be a source of infection. For that, one of the disadvantages of sludge is the deficiencies and imperfection in the biological and thermal treatment, which will lead to a physiological problem (Du and Li 2017). By setting these critical advantages, unsafe outcomes emerging from the use of sludge can be controlled. The clients can know about the depiction of the usage of sludge as a two-sided blade and governments ought to carefully deal with this theme to upgrade the points of interest as opposed to the drawbacks (Du and Li 2017).

1.12. Risks arose from using sludge and the effects on plants & soil

All the literature clearly indicated that the outcomes arising from using sludge are more advantageous than disadvantageous as it tells the whole story of the usage of bio-solids as an organic fertilizer. Issues associated with sludge hazards are linked to all other levels and go on to be a topic for discussion to examine the outcomes of the use (Du and Li 2017). This section will abbreviate the role of the bio-solids and their effect on soils, animals, plants, and for sure on humans as the end-user for the agricultural products. For that, it requires further elaboration to answer the question of what comes after sludge production.

To answer this question, it is needed to emphasize some of the expected risks like distressing the groundwater eminence via the leakage of nutrients (Firmansyah, Spiller et al. 2017). To discuss this topic, it should be necessary to recall and discuss some nutritional features of sludge. Sludge frequently comprises about 2% of phosphorus and 5.5% of nitrogen (on basis of dry matter). The whole nutrient content of the sludge is distributed depending on its moisture substance that is 90% so that one ton of sludge will give approximately 50 kg of N and 18 kg of P (Public Work Authority 2017). Sludge discharges most of its nutrients gradually, and in the time of appliance, about 50% of P and 25% of N is accessible for plant growth, equal to about 9 kg P/t and 12.5 kg N/t. If the least average optional rate of appliance begins at 5 t/ha, then this offers approximately 90 kg P/ha and 250 kg N/ha. It indicates that 45 kg P/ha and 62 kg N/ha would be supposed to be accessible for crop uptake, as summarized in Table 4 P (Public Works Authority 2017). The rate of application depends on the actual nutrient content of the sludge and the fertilizer requirement of the crop. The latter will depend on soil fertility, which will increase with the regular application of sludge due to the residual value of sludge nutrients P (Public Works Authority 2017). Reliably, sludge application rates to any field must supply nutrient levels that don't surpass crop necessities. This methodology prevents amassing of nitrogen which may drain (because of rainfall or normal irrigation practices) and may affect the quality of groundwater (Public Works Authority 2017). A top rate of N addition commonly adopted for organic manures in Europe is 250 kg of nitrogen per hectare, or if the field of the application lies in an area vulnerable to nitrate pollution, the application rate is limited to no more than 170 kg N/ha P (Public Works Authority 2017).

Table 4: Nutrient content of sludge and nutrients applied by sludge at a recommended rate of 5 t/ha.

	Nutrient content of sludge		Nutrients applied by sludge at the recommended rate of 5 t/ha.	
Nutrient	**Dry matter basis (%)**	**Fresh basis (90% ds) (kg/t)**	**Total nutrients (kg/ha)**	**Available nutrients in the first year (kg/ha)**
Nitrogen (N)	5.5	50	250	62
Phosphorus (P)	2.0	18	90	45

Nitrogen in sludge is discharged gradually through microbial act in the soil, and this benefits crops as the availability of nitrogen for uptake is better distributed throughout the growing cycle (Tambone and Adani 2017). With chemical fertilizers, such as urea, there is immediate high N availability with the risk of leaching loss, if not absorbed by the plant. Therefore, it is common practice to apply fertilizer in split doses.

In comparison with sludge cake, heated dry pelletized sludge requires a more extended period to physically break down till the soil microbial activity can act on the sludge organic matter. It can reduce the immediate nutrient availability but will result in better residual values later in the growing season (Tambone and Adani 2017). P is not easy to be got like N and is frequently bound sturdily in the particles of the soil, particularly under calcareous soil states, as in Qatar, for example. Thus, the content of phosphorus in the bio-solids is not frequently a limiting factor in reviewing the sludge appliance rate.

With the standard ratio of 5.5% nitrogen, the appliance rate of sludge must be 4.5 tons per hectare (proportionate to five tons per hectare or 8.3 m3/ha of dried pellets of sludge) to provide 250 kg N/ha. Where the soils are infertile, as in Qatar, and as nutrient discharge from dried sludge is expected to be comparatively slow, then bigger rates of the appliance, up to 10 t/ha (16.6 cubic meters per hectare) might be appropriate without damaging the crop or any hazard to the eminence of groundwater (Tambone and Adani 2017).

However, the optimum application rate for different crops can only be determined accurately by conducting field trials. This can aid in adequate consideration and assessment of the effects of local climatic soil conditions and farming. The distributed dosage will reflect very substantial and good growth in plants. Most of the literature and research papers noted this positive impact (Nartey, Amoah et al. 2017). This prioritized mark will direct us to the subsequent precedence to check the effects of other hazardous components on the whole cycle, as in the case of heavy metals. Several researches were completed to assess the impacts of weighty metals on diverse crops and dissimilar kinds of soil. These researches gauged the impacts of heavy metals residues on plants as this is the major significant point that will aid us to realize the transfer of these components in the food chain. It is further needed to point a serious issue that such studies have to swathe an extensive age to give a useful assessment.

Moreover, a number of heavy metals like copper, iron, and zinc are symbolizing the necessary trace components which are needed by the plants in diminutive quantities (Singh, Gautam et al. 2011).

A study done on raspberry (*Rubus ideas L.*) three years ago by using different applications of sludge to check the effect of these rates on plants growth and residues of heavy metals in both soil and leaves showed a significant improvement in growth without any irregular increase in the concentration of heavy metals. The study further noted the essentiality to use the sludge according to the rules without any adverse impacts on both soil and plants (Angin, Aslantas et al. 2017). Another study arranged by using a couple of different types of sludge to compare it against the compound fertilizers of NPK in a paddy crop *Oryza sativa* managed to check the concentration of nutrients and heavy metals along with the effects on the microbial activity within the soil (Nartey, Amoah et al. 2017). The results reflected a significant increase in nitrogen and carbon for the sludge treatment along with enhancement in the microbial activity with a variation between the two types of sludge. There were also better results for the well-treated kind and without major changes in the concentration of the toxic elements after a trial of five years (Liu, Liu et al. 2017).

Another study was done in a poor urban soil fertilized with biochar sludge and planted with grass (Yue, Cui et al. 2017). The results showed a significant enhancement in the soil properties. Specifically, ratios of the essential macro-elements like nitrogen & phosphor. There was also an increase in the concentration of heavy metals which 97 % of these levels were biologically unavailable. The study also recommended the use of sludge to improve poor urban areas and enrich the soil. Furthermore, the study undoubtedly stated that there would be no adverse effects of heavy metals since the use of sludge is within limits (Yue, Cui et al. 2017).

Investigators conducted a study on willow (*Salix sp.*), which is the most recommended tree for remediating textures of soil after repeated sludge treatments. The study aimed to investigate the usage of sludge with varied sizes on the soil qualities and phytotoxicity by adding ratios of 3 and 9 tons/hectare. The obtained results showed a significant enhancement in soil properties regarding the proportions of Nitrogen, Carbon, humus contents along with a visible improvement in microbiological activity. The growth of the trees of willow was much better in terms of the tree biomass and also in the size of leaves and ability to manage phytotoxicity by trees. In a nutshell, the usage of sludge gained a positive impact on both soil and trees (Urbaniak, Wyrwicka et al. 2017).

The last example is about an experiment on an aromatic shrub of *Ocimum basilicum* to test the effect of using additional sludge application to bacterium inoculum on the soil properties and plant growth in sodic soil. The study had an application rate of five tons/hectare and two strains of bacteria isolated from the trial field area. The study concluded that the use of sludge and bacterial inoculum had a very positive impact on soil richness and properties. Additionally, it enhanced the growth and oil content of the holy basil shrub (Trivedi, Singh et al. 2017).

It is quite clear that in general, the impacts of using the sludge are conditionally considered positive on plants and soil. Moreover, if ever the application rates were investigated and added by following the recommended dosage and base on the soil analysis, sludge can positively improve the health of soil and plants. Correspondingly, the hazards of heavy metals and their negative impacts cannot be avoided if users of sludge failed to arrange for an appropriate sampling of sludge and soil. Additionally, the lack of scientific appliance procedure will result in erroneous outcomes, which will affect not only plants and animals but also human health (Singh, Gautam et al. 2011). Nevertheless, the incidence of heavy metals in sludge is mostly considered to associate with business linkages to the sewer. Elevated levels can transpire in sludge from sewerage catchments that serve big industries, and where there is no effective control of discharge. Nonetheless, the sludge will unavoidably hold some concentrations of heavy metals obtained from the utilization of domestic products such as water supply pipes, hygienic stuff, cosmetics, pharmaceuticals, and many more. Heavy metals in human feces are also essential trace elements in foods. Practically, heavy metals are seldom a constraint as the nutrient needs of crops restrict the sludge rate application. In Europe, this limits sludge application to 250 kg N/ha, although in areas vulnerable to water pollution by nitrate, a lower maximum limit of 170 kg N/ha is set (Public Work Authority 2017). Another possible harm to humans and the environment appears from the risk of disease transmission. Guidelines and regulations adopted in many nations identify the treatment needs to minimize the hazards and offer the utmost acceptable approaches to thwart unfavorable effects on human health and the environment. The existence of various global scientific research and practical experience over the decades has led to the formulation of controls and policies. However, the precautionary principle has been recently applied to sludge due to the prejudices of the global users, resulting in quality standards and controls being progressively tightened in many countries and sludge management becoming increasingly challenging and costly (Yoon, Kim et al. 2004). It creates a conflict between waste management policies encouraging recycling and discriminatory quality standards that impose unnecessarily stringent and costly requirements that often direct sludge producers to disposal options rather than use it (Yoon, Kim et al. 2004).

The risks of major diseases can be realized by verifying the identified and necessitated bioassays to be completed for the product, which is approximately similar in all global standards. These instructions such as the US standards, which are the commonest in the world identify the present level of hazardous biological agents for both classes A and B as follows: Class A: Fecal coliform <1,000 MPN per g ds; Salmonella <3 MPN per 4 g ds**;** Enteric viruses <1 plaque-forming unit per 4 g ds; Helminth ova <1 viable per 4 g ds; and Class B: Fecal coliform 2 x 10^6 MPN per g ds.

While European guidelines limit the parasitic and pathogenic values, this is not regarded as necessary due to the assumption that a treatment process convenes to the process provisions. The adoption of restrictions on use could control the potential transmission of disease. For instance: crops eaten uncooked cannot grow for ten months after application and animals cannot graze pasture for three weeks after application (Public Work Authority 2017).

The Fecal coliform or the thermos-tolerant coliform is a gram-negative bacterium, which contains many genera like Escherichia. The test is more likely to be an indicator of sludge contamination with a specific species of E. coli. It will point out that the sludge might encounter the presence of other types of pathogens which perform a risk on animal and human health as it can affect their intestines. It can also be transferred via direct exposure or by grazing on plants fertilized by contaminated sludge. Coliform bacteria are not dangerous, but scientists discovered one of the strains of E. Coli of 0157: H7 that can cause major problems for human health as it produces harmful toxins, and the test will be a good alarm to avoid any outbreak of such diseases (Fuhrimann, Nauta et al. 2017). Similarly, Salmonella is another genus of bacteria causing typhoid and also severe diarrhea that usually takes one week to be healed mostly; unless the infection is acute and related symptoms might appear like dehydration. This genus of bacteria belongs to the family Enterobacteriaceae, which contains many types (Gao, Deng et al. 2017). The most critical contaminants of sludge are *S. enterica* & *S. bongori*. The infection mostly comes from undercooked contaminated food, and because the effects are considered to be minor as compared to E. coli, it's not included in the USEPA standards (Lamas, Miranda et al. 2017).

The tests of enteric viruses are only specified in American standards. These infections are sensitive to thermal treatment, and this is the known reason for gastroenteritis. The USEPA included these groups of viruses due to its ability to infect the human even with a dose of one rotavirus. The source of infection could be either by contact or by fomites (Tozzoli, Di Bartolo et al. 2017).

Lastly, the helminths worm is a parasitic worm known in the literature as helminthiases with microscopic eggs and is usually found in sludge, if it is not treated thermally. This type of worm, like *Ascaris* worm, is traditionally creating physiological harms in the gastrointestinal tract and might cause anemia. However, it can't tolerate thermal treatment (Rojas-Oropeza, Hernández-Uresti et al. 2017).

For the microbial presence, it could be concluded that the tests specified to be done regularly for the thermally treated sludge are mostly a sort of insurance for the safety of the thermal system. Otherwise, around the whole world, the problems of infective microbial causes in sludge are nowadays considered manageable, and this management comes through several essential processes of thermal treatment.

1.13. Thermal Treatment, Aerobic, and Anaerobic digestion

The making of sludge passes through numerous procedures to make it useful, and to decrease the risk of possible dangerous pathogenies. It also makes it a more steady mix and benign to be applied, these approaches might differ from one state to another based on procedure or contents. Still, in general, the same concept is almost similar. To cover the topic of using sludge, the following three major steps in this business should be discussed (Bartkowska 2017).

1.13.1. Anaerobic Digestion

The biological process is used globally and usually arranged to allow the microorganisms' digesters of different bacteria types to break down the bio-solids in the sludge to further stabilized substances, with no existence of oxygen as these natural agents are intolerant to oxygen. This sequence of processes functions significantly on the biodegradable instruments (a significant number of cells) to convert it to solid matter, and the treated sludge will serve as a rich soil conditioner. The process will release energy, CO2, CH4, and water as well. In most cases, the process is frequently completed in a closed tank to avoid the entrance of oxygen. The resulting products from the conversion procedure symbolize the link between consortiums of four different bacterial types with a varying functionality of methanogenic, acetogenic, syntrophic, and fermentative bacteria. The process usually fundamentally operates in two similar trails that commence by liquefying the complicated or insoluble compounds and generating biogas from the intermediate all along sludge humification (Bartkowska 2017).

One of the significant benefits of the anaerobic process is, in addition to mineralizing the organic matter, it generates biogas. It became the most striking bio-product which led to the interest of commercial companies and scientists for decades as a reliable source of clean energy and for the sake of boosting the anaerobic process.

Many nations have intentionally commenced growing plants such as maize, which are known to activate the anaerobic process. The essentiality of this process is that it increases the capability to generate biogas from the bi-solids, and this has various uses in the agro-industrial financial system (Dai, Huang et al. 2017).

For further elaboration about this process, it is needed to know that it starts with the hydrolysis of carbohydrates and proteins. The working anaerobes in this stage are streptococcus & enterobacterium to turn the compounds into monosaccharides and also acids like amino acids and fatty acids. This process moves together with another group of hydrolytic bacteria which are responsible for producing hydrolases enzymes like (amylases, lipases, and proteases). Only fifty percent of the biomass degrades at this stage due to the presence of some stubborn polymers like cellulose which functions as a significant regulator of sludge digestion. Enzymes production and the other physical and chemical characteristics of the particles like size or pH are considered to be parameters in this stage (Dai, Huang et al. 2017).

The next step would end up with arranging the sludge for a different group of obligatory anaerobes like Pseudomonas, Micrococcus, Bacillus, and Clostridium to work on the sludge. This arrangement process, called the acidification phase is well known to engineers because of the bad smell from the production of Ammonia and H_2S. It is essential in killing many pathogens as ammonia is considered to be the most effective chemical reagent in sterilizing biological agents. This stage starts with the acetogenesis bacteria to turn the product of the previous step to organic acids like acetic, butyric, propionic, formic, and pentatonic acids along with other chemicals like alcoholic ethanol and methanol and some aldehydes and of course CO_2 and H_2. The major components of this stage are the substrate of methanogens that becomes acetates, carbon dioxide, and hydrogen. The high hydrogen concentration enables the acetogenesis bacteria to work on the products, which are the source of the bad smell (Alleman and Berman 1984).

The acetogenesis process represents the efficiency of biogas production and seventy percent of the methane produced in the stage along with eleven percent of hydrogen, which is a high concentration that has a toxic effect on the bacteria in this process (Alleman and Berman 1984). Therefore, interference from another type of bacteria that utilize methane which is autotrophic methane bacteria is essential. The acetogenesis stage is carried by other types of bacteria of Syntrophomonas and Syntrophobacter. The last step is methanogenesis which is led by methanogenic bacteria to produce methane gas. The whole process substrate is the output of the previous phases. The produced gas is rich in carbon dioxide, and the sludge would be very much steady and set for further treatment to manage it (Public Work Authority 2018).

1.13.2. Aerobic digestion

This method is a representation of another paramount process organized by the digesters. These digesters work on bio-solids to make them steadier and to minimize the sludge volume with the existence of oxygen. The digestive microorganisms use oxygen from the atmosphere in a process known as composting. The final products are mostly sulfur, phosphate, water, CO_2 and nitrate, as well as heat, which emanates from the oxidation of the nitrate, sulfur and phosphate into Co2 and H2O. The generated sludge is then made ready for dewatering, thickening, and thermal treatment process to make it utilizable. The process is completed by various microorganisms which consist of 95% of bacteria. The remaining organisms include five main groups of fungi, algae, protozoa, metazoan and filamentous bacteria; which can biodegrade cellulose, lignin in an enhanced way, instead of bacteria or work for the improved lucidity of the sewage (Bartkowska 2017).

1.13.3. Thermal Treatment

The essential advance is disinfecting the sludge with heat. There are a few kinds of thermal treatment. However, the best one is by the hot sir which colossally lessens the volume and executes the rest of the pathogens. In some productive new structures for the sewerage stations, they consider it as the spotless field strategy as it kills all the related organic agents and in class-A sort. It further moves as far as possible, even after shaping the pellets to guarantee the end of any inherent dangers (Hall, 2017).

1.14. Examples of Common Calculations in the Management and Control of Agricultural Use of Sewage Sludge (Hall, 2017)

Works of the literature revealed few mathematical practices and equations to be used to satisfy the theoretical part in tackling this topic significantly and to simplify follow-up the arrangements by governmental authorities. These equations are to be applied in conjunction with sampling and analyzing processes as a base. The outputs of both methods can give a sufficient level of information about the practical part of the application, which will be evidenced by the soil analyses. For highlighting this important topic, it's essential to include the most relevant calculations concerning the bio-solids:

1.14.1. Equation 1 - To calculate sludge volumetric application rate

For control of the addition of nutrients and heavy metals, the application rate is determined initially on a dry solids basis. For sludge application by the farmer, this needs to be converted to a spreading rate calculated on a wet sludge basis.

Application rate (t ds/ha) x 100 = Application rate (t/ha fresh sludge) Sludge dry Solids content (%)

For further clarification about the use of this equation, researchers need to keep in mind that if the target rate of application is 4.5 t ds/ha, for example, and the sludge has 90% ds, the rate to be applied by the farmer is 5 t/ha. The density of dried sludge pellets is

0.6 t/m^3, so the volumetric application rate is 8.3 m^3/ha, i.e.:

4.5 x 100 = 5 t/ha x 0.6 = 8.3 m^3/ha

90

1.14.2. Equation 2 - To calculate heavy metal additions

To ensure that heavy metal additions are within permitted rates when sludge is applied at the target rate of application:

Sludge concentration (mg/kg ds) x Application rate (t ds/ha) = Metal addition (g/ha)

This means that if the sludge concentration of zinc is 900 mg Zn/kg ds and the target application rate is 5 t ds/ha, then the quantity of zinc applied is 4,500 g/ha, i.e.:

900 x 5 = 4,500 g Zn/ha

1.14.3. Equation 3 - To calculate the increase in soil concentrations of heavy metals

To predict the approximate increase in soil concentration of heavy metals added to the soil by sludge application. This can be done after each use on the sum of massive metal additions by all previous sludge applications to monitor the theoretical increase in soil concentration about maximum limit values. This should be confirmed periodically by soil sampling and analysis to determine actual soil concentrations.

Metal addition (g/ha) = Increase in soil concentration (mg/kg)

Soil volume (m3/ha) x Soil density

The addition of zinc to the soil is 4,500 g/ha (determined by Equation 2) and is multiplied by the weight of soil per hectare. The volume of soil is calculated by a hectare (10,000 m^2) multiplied by cultivation depth (e.g. 25 cm), giving 2,500 m^3/ha, and then adjusted for the density of soil (assume 1.3 t/m^3), giving 3,250 t/ha. The amount of zinc applied is divided by the weight of soil to give an increase of zinc concentration in soil of 1.15 mg Zn/kg, i.e. (after the cancellation of common factors):

4,500 = 1.38 mg Zn/kg soil

2,500 x 1.3

1.14.4. Equation 4 - To calculate the number of years before soil limit value is reached

It is useful to check the number of applications that can be made to a field before the maximum permitted soil limit concentration is reached. Initially, this would be based on the soil analysis from samples taken before sludge is applied for the first time. Subsequently, the latest soil analysis should be used. By doing this calculation for each of the heavy metals, the most limiting heavy metal can be identified. This is necessary as the ratio of heavy metals in sludge differs from that in soil. This will dictate the total amount of sludge that can be applied, and assuming that sludge is applied at a maximum frequency of once per year, this gives the minimum number of years until the most limiting soil limit value is reached.

Soil limit value (mg/kg) – Background soil concentration (mg/kg) = Years to soil limit Heavy metal increase (g/ha)

Within the same context and to highlight this equation, researchers, can assume for example that the background concentrations of heavy metal in soil (e.g. 110 mg Zn/kg - determined by soil sampling and analysis), is subtracted from the maximum soil limit concentration (300 mg Zn/ha), and divided by the increase in heavy metal content of soil by an application of sludge (e.g. 1.38 g/ha, determined by Equation 3), to give the number of years of annual application to reach to the soil limit value for zinc, of 138 years, i.e.:

300 – 110 = 138 applications to limit value = minimum number of years

1.38

1.15. Bio-solids production in Qatar

The treatment stations have become necessary components of both waste disposal and green infrastructure to accommodate the increasing sludge quantities generated by urban populations (Kacprzak, Neczaj et al. 2017). The resulting byproducts of treated sewage effluent [TSE] is likewise a useful resource for both urban greenery programs and agricultural production (Fischer Filho, Dalri et al. 2017) not to mention the sludge products or bio-solids as mentioned. In the interest of sanitation, governments impose standards for multiple treatments of wastewater requiring either aerobic or anaerobic digestion, along with physical dissolving and purification, chemical treatment, thickening, dewatering and thermal treatments, and many other efficient, modern techniques to enhance sludge quality (Fytili and Zabaniotou 2008).

In compliance with the above and by owing to necessity, Qatar has constructed and commissioned a Thermal Dryer Plant at Doha North STW (DN STW). This plant is capable of producing Class A [ie. Pelletized sludge suitable for unrestricted uses], Class B [ie. Sludge cake] and TSE water (Hall, 2017). The authorities have approved the use of Class A as an organic fertilizer for ornamental plants and landscaping purposes only (Rao, Thomas et al. 2017). The estimated quantities to be generated every day is almost 100 tons, whereas 80 tons are used to produce Class A. The remaining portions are for Class B. Government authorities in Qatar specified the potential practices to use these quantities for landscape construction, as in recent years, there has been a significant increase in extending the footprint of Qatar's green infrastructure [eg. Public parks, streetscapes] in the major cities of Qatar (Hall, 2017). This has also been mostly possible due to ample supplies of TSE made available for landscape irrigation. Annual year-on-year operations and maintenance [O+M] of these green assets to international practice incorporate or encourage the use of sludge in the public realm [eg. Public parks, open spaces, and gardens, streetscape planting]. Qatari authorities are strategically aiming to enrich the barren soils in the country with these recycled bio-solids. Doha North STW is providing a centralized sludge thermal drying facility to treat all of Ashghal's sludge arising in Qatar with sludge being imported from the main STWs of Doha South, Doha West, and Industrial Area and the small STWs serving Dhakhira and Shahaniya.

Thermal drying was selected to produce sludge of the highest quality and thus maximize opportunities for beneficial use of sludge on land as an organic fertilizer or in combustion processes as a renewable energy source.

1.15.1. Description of the sludge production Process at DN STW (Engineering 2017)

The generated sludge from the biological activated sludge at all STWs of PWA, including DN STW, undergoes the following treatment stages:

First, there is a thickening of centrifuges to reduce the water content of sludge; secondly, aerobic digestion occurs to stabilize sludge to the Class B category. Additionally, there is dewatering of 18-21% to dry solids sludge cake, utilizing centrifuges to minimize water content further for ease of transportation, storage, and application. The generated sludge meets the specifications of the Class-B category at this stage. At (DN STW), class-A thermal dryer pelletized sludge process is applied for all class-B sludge produced at all (STWs) including (DN STW).

The dewatered cake is delivered to Doha North STW by trucks, which enter an elevated area dedicated to the Lorries and tip the cake into one of ten reception bins. The dedicated space will minimize the contamination of the trucks with dewatered cake. The reception bins are enclosed to control odor. The roofs of the containers slide open, and the cake is tipped vertically into the boxes. At the opposite end of the drawers, at a lower level, there are ten vertical doors, where only one is to allow access by front-end loaders. Only one bin is tipped once, and only one container is emptied by the frontend loader at any time. These 'operational' bins are subjected to high air extraction rates, along with the restricted openings, to prevent odor from escaping; a thing that can adversely affect the required odor levels at the site boundary. The front-end loaders deliver the dewatered cake into one of three live-bottomed loading hoppers. These automatically transfer the cake to conveyors which discharge into a chain of conveyors, lifting the cake into the dryer feed silos.

1.15.2. Thermal Drying

The thermal drying facility has been based on well-proven equipment incorporating the current safety standard compliant with the ATEX regulations. The dryers selected are the Swiss Combi sewage sludge dryer; it is a direct convective drum dryer that features an indirectly heated patented Closed-Loop design (Daly, Fenton et al. 2019).

Dried sludge pellets /granules size is 3-6mm diameter, while the type of heating employed is LPG. The heater installed capacity is 6.5 MW, and the gas consumption per kg H_2O removed/hour is 0.91 kW/kg H2O.

1.15.3. Feed Arrangements

Four live-bottom silos, one per drying stream, receive the dewatered and imported sludge. Distribution conveyors on the top of the silos allow distribution from any of the duty and standby conveyors to any of the silos. Each silo is equipped with a live bottom delivering dewatered sludge to a collection screw, which transfers the sludge to the hopper of a progressive cavity dryer feed pump (Daly, Fenton et al. 2019). The dryer feed pumps are also fitted with bridge breakers to prevent any hold-up. The lengths of the discharge pipes from each of the feed pumps are minimized and have swept bends to reduce the pressure drops and reduce the potential for blockages.

1.15.4. Sludge Path

Dewatered sludge is pumped at a variable rate to the twin shaft mixer of the dryer. Before being fed into the drying drum, the dewatered sludge is mechanically mixed in the twin shaft mixer with recycled dry sludge to form a smoothly flowing material. This material is then transferred to the drum by the feed screw. The drying drum is specially designed for sludge (Daly, Fenton et al. 2019). Hot air circulating in a closed loop passes directly through the drying drum and evaporates the water content of the sludge. Residence time in the drum can be varied by adjusting the rotational speed of the drum and adjustment of the internal baffles and discs within the drum. The drum outlet temperature is set to a level to ensure drying to a level of, say, 90% to 92% dry solids. After passing through the drying drum, the dried product is separated from the drying air in the filter with an integrated cyclone. The dried product is discharged through the rotary valve and the discharge screw towards the first cooler. After the product has cooled down, it is taken to the screen sizer through the bucket conveyor. A discharge screw conveyor is provided for the removal of the product from the drying air filter to a skip located outside of the building. The vibrating screen sizer divides the dried product into four fractions (reject, large, medium and beautiful). The large and a portion of the medium product is conveyed as end product into an auxiliary cooler and eventually to the end product pneumatic transfer system. The other part of medium size and exceptional size product is used for back mixing (Daly, Fenton et al. 2019).

1.15.5. Recycling Product

The fine and a portion of medium grain product separated by the screen sizer is transferred to the recycling silo and fed via dosing screw conveyor into the twin shaft mixer.

The heat energy is generated in a combustion chamber fired by LPG. There is a single burner, combustion, thermal oxidation, and heat generation unit. The combustion air source (primary air) comprises ambient air together with filtered aspiration air drawn from the dryer product handling components (Daly, Fenton et al. 2019). The secondary combustion air source is the drying process gases that are blown into the combustion chamber as dilution air. These dryer gases are incinerated within the two-stage high-temperature combustion chamber of the drying plant. The combustion chamber is operated at approx. 900°C in the first stage and 825°C in the second stage to achieve the lowest possible emission values. The retention time in the combustion chamber is approximately two seconds (Daly, Fenton et al. 2019).

Further treatment or oxidization of the dryer off-gases is not necessary. The hot flue gas flows through the heat exchanger where its thermal energy is transferred to the air/vapor mixture circulating in the closed drying air loop. The cooled flue gas (exhaust air) leaves the heat exchanger and, via the exhaust air blower, is exhausted into the atmosphere through the exhaust stack (Daly, Fenton et al. 2019).

1.15.6. Drying Air Circuit

The principle is applied to the drying air loop whereby it is kept under slight negative pressure at points where dust, vapor or odor emissions could occur. This ensures their retention within the process and that any dirt is recycled with incoming sludge (Daly, Fenton et al. 2019).

The heat energy required for drying is imparted in the air-to-air heat exchanger to the drying air circulating in the closed drying loop where its temperature is raised to about 400 °C before it enters into the drying drum. The drying air directly evaporates the water from the sludge, and the resultant vapor leaves the drum together with the wind. The air/vapor mixture is separated from the dried sludge in the combined cyclone/filter unit and returned to the heat exchanger for reheating. A water injection module (amortization) is included in the drying air circuit. This is a feature, which allows the oxygen level to be reduced on start-up to that of normal operating conditions before the introduction of sludge. It can also be used to maintain drying air temperatures and oxygen levels during plant shutdown. The sequential introduction of water into the drying loop improves process control and allows full load test of the plant during commissioning without the need for sludge feed (Daly, Fenton et al. 2019).

1.15.7. Aspiration/ Combustion Air

As stated above, the elements from which unpleasant odors and dust might escape are operated under slight negative pressure, and the plant is kept free of perfumes and dust. Condensation of vapors in the conveying elements is also avoided. The first air blower generates this negative pressure (Daly, Fenton et al. 2019). The aspirated air is cleaned in the filter vessel and afterward added to the combustion air (central air) of the dryer combustion chamber. The dust separated and collected in the filter is transported via filter screw to the twin shaft mixer.

1.15.8. Final Product

Downstream of the final product screw is an auxiliary cooler followed by forward conveying towards one of any three dried product silos. The auxiliary cooler ensures the reduction of the final product temperature to 40°C (Daly, Fenton et al. 2019).

1.15.9. Dryer Exhaust

The exhaust air blower exhausts to the atmosphere through the exhaust stack. With the dryer's integrated thermal oxidizer, the emissions to the atmosphere are within prevailing regulatory requirements and will comply with, for instance, MoE Standards clause 2.1.4.1 for granulating fertilizer plants. No other additional emissions treatment equipment such as a regenerative thermal oxidizer (RTO), bio-filter, or chemical scrubber is required. The destruction of unpleasant odor is ensured by combustion at high temperatures. Sewage sludge comprise silane components that evaporate and partially crack in the hot atmosphere of the drying drum. When treating the gases from the dryer, the silane components will be crystallized in the tropical zones (600 – 900°C) of the combustion chamber/heat exchanger. The heat exchanger design provides easy cleaning and access. The clearance of the ceramic honeycombs of a regenerative thermal oxidizer (RTO) is much smaller than the removal of the specially designed heat exchanger of the offered drying plant. Deposits in the heat exchanger can easily be cleaned off its plates and the combustion chamber surfaces. Experience from Swiss Combi owns and operated plants indicate a cleaning interval of six months (Daly, Fenton et al. 2019).

1.15.10. Plant Control

A PLC-based control system is located in the dryer Motor Control Centre. These monitor and regulate the drying line and interface with peripheral equipment. Due to the high degree of automation, the plant can be operated without permanent manning and supervision (Daly, Fenton et al. 2019). All critical safety parameters are continuously monitored, and safety interlocks in the control system prevent unsafe operation, even under 'Manual' operation.

1.15.11. Dried Product Handling & Storage

The dried product from the four drying streams is collected and conveyed to one of three dried product silos. These silos can discharge to either the bagging plant or discharged directly into a truck. A fortification system has been designed to adjust the nutrient composition of the dried product to that of commonly available fertilizer; NPK ratio of 20:10:10. This is achieved with the addition of urea and potassium chloride. These fortification chemicals are added via a metering screw before a mixing screw upstream of the bagging facility. A third silo and metering system is provided for the eventuality of a third fortification chemical being required. After mixing with fortification chemicals, the dried product is transferred to a bagging facility with two streams operating as a duty and standby. The filled bags are sealed and palletized. The loaded pallets are transported to the storage buildings by a forklift truck (Daly, Fenton et al. 2019).

1.16. Soil in Qatar

The State of Qatar land is a small, unbroken, and limestone peninsula, which extends north, precisely from the borders of Saudi Arabia towards the Arabian Gulf (Oledinma and Aktas 2017).

Geological and geographical soils survey identified the Qatari soils over the country as mostly lithosol, which is a term used to define rockery soils lacking real horizons and also not deep (Webb, Rosenzweig et al. 1993). They are approximately shallow, with an identical depth of around 10-30cms-only with few sandy loam pockets known as 'rawdha'. Such infertile, calcareous sandy loams are surfaced with rock debris, whereas this blanket of fragmented rocks is settled above limestone bedrock (Al-Thani and Yasseen 2017). Furthermore, few lands with high salinity are commonly known as Sabkha soil, which is not suitable for cultivation. Qatar has two areas of Sabkha lie in Dukhan and Umm Saied with a high content of gypsum mineral. The broad anticline at the edges of the peninsula is a unique structure, whereas the approximate apical point is only one hundred meters above sea level (Al-Thani and Yasseen 2017). This limey structural type of soil made the surface sediments subjected to winds, especially the north wind. It controls the blown sand and dune sand at the same time.FAO studies estimated 2.5 % of the total land of Qatar as suitable for agricultural purposes, which are around 28,000 hectares planted mostly with annual crops like vegetables or green rations (Babikir, 1984). Such barren limestone types of soil are ideal for gas production, but they cannot be broadly exploited for agricultural purposes. Many parameters are affecting the agrarian movement and the green kind of cover that can thrive in such conditions, like the indigenous plants. It's essential to know that the salinity of soil in Qatar can reach levels of 200 DSM with a harsh climate and summer temperature, which might go over 50 degrees. By considering the above issues and by checking the remaining abiotic factors including drought as there is a lack of pure water and the rainfall level is less than 80 mm. Hence, it's essential to decide to use a rich organic material to improve the soil properties and to activate the beneficial soil microorganisms which play a significant role in enhancing the growth conditions and the availability of nutrients as many kinds of literature affirmed that the harsh climate conditions caused a host of changes for these vital biological agents. The bio-solid should be very much recommended to handle such enhancement (Al-Thani and Yasseen 2017).

CHAPTER 2: MATERIALS AND METHOD

Experiment No. 1 Temporal Characteristic (Chemical & Physical) of Qatar's Biosolids of Class A.

(a) Sampling and Preparation

Samples of four bags weighing 10kg each were randomly collected from freshly produced biosolid at three-month intervals; 03/02/2018, 03/05/2018, and 03/08/2018. Samples, representative of the material, were packaged with labels indicating the material type, date produced, and source. These were randomly collected in their original sealed packaging from the production site at Ashghal's Doha North Sewage Treatment Plant (DNSTP) marked with numbers, labels for each sample, and experiment number. All the samples were subjected to qualitative and quantitative physical investigation and detailed chemical and spectrographic analyses as necessary.

(b) Physical analysis.

Particle size analysis (Hydrometer sedimentation) Materials and Methodology.

The methodology used was Particle-Size Analysis of Soils (ASTM D422-63 2007). The physical analysis involved inspecting the particle sizes of the pellets through the mechanical method of sieves. The standard stainless steel sieves provided reliable sieving results for determining the granular pellets' particle-size distribution (gradation). Particle size distribution is critically essential in assessing the performance of the material in use. The producer expressly and precisely indicated the appropriate mesh-specific requirements (dried sludge pellet/granule size range of 3-6mm diameter) (Public Work Authority 2017). The entire apparatus consisted of a configuration of a balance, standard sieves, a hydrometer, a cylinder for sedimentation, a water bath and stirring apparatus, a mechanical sieve shaker, and a drying oven. The procedure commenced by constantly drying the samples in the oven at 110 ± 5 °C

A sample of 1 kg of dry aggregate was sieved using different sieves of different openings to help determine the particle-size distribution. The sieving process was carried out right after the drying process. It involved mixing the sample in a sieve and shaking it using the mechanical sieve shaker for a short period. The passed quantities were marked categorically to allow the sieved sample to move to a smaller sieve if not more than one percent of the total sample mass remained. The sieves used were 75, 63, 50, 37.5, 25, 19, 12.5, 9.5, 4.5, 2, 0.475, 0.075 mm opening sizes. These ensured that the sieved material met the specified criteria alongside calculating the mass of a passed quantity of the tested sample (ASTM C136-06 2006).

The sieved particles were passed through the smallest sieve of 2.00mm, and a hydrometer was used to determine the relative density of liquids in the particles. The prepared 1000ml of distilled water and a dispersing agent of 40gm sodium hexametaphosphate per liter in a sedimentation cylinder were placed in a water bath. Rh 152H hydrometer was immersed when the temperature was constant, and the reading was recorded after a while. The composite correction defines the variation of the readings from zero. The hygroscopic moisture was also measured by weighing 15g in a glass container and drying it in the oven at 110 ± 5 °C then weighed again along with recording the masses. The dispersion of the biosolid sample was determined by weighing and putting 100g of the air-dried sample into a 250 ml beaker and mixed with 125ml of dispersing agent and then left to soak for sixteen hours. The mixture was then stirred for one minute using the stirring apparatus for further dispersion of the sample before transferring the slurry to the sedimentation cylinder, where it was mixed to 1000ml using distilled water. The mixing process for the solution involves turning the cylinder upside down for one minute. The hydrometer readings were taken at specific intervals of 2, 5, 15, 30, 60, 250, and 1440 minutes after dispersion relative to the suspension temperature recordings after each reading. After recording the hydrometer readings, the suspension was transferred to the second sieve, washed with distilled water then transferred to the oven for drying at a temperature of 110 ± 5 °C. Subsequently, the material was sieved through smaller sieves to ensure its compatibility with the specified procedure. The sieving process also involved computing the total percent of the total sample passing each sieve by dividing the passed oven-dry sample overall mass by the overall mass of each sample and multiplying the result by one hundred. The hygroscopic moisture correction factor was calculated as the ratio of the mass of samples dried in the oven and the mass of the air-dry sample before the drying process. The value is always less than one. The percentage of soil in suspension was calculated using the equation:

Sample of oven-dry mass = Air dry mass * Hygroscopic moisture correction factor.

Mass of total samples = $\frac{mass\ of\ oven\ dry\ sample}{percentage\ passing\ sieve\ no.10} * 100$

Biosolid remaining in suspension percentage P = (Ral W) * 100

Where (a) is the correction faction, (r) is hydrometer reading with composite correction, and (w) is the mass of oven-dry biosolid. For the diameter of biosolid particles, we applied Stocke's law to calculate it as follows:

$$D = k\sqrt{L/T}$$

Where D represents the diameter of biosolid particles, and L is the distance between the suspension surface and the point where the hydrometer measurement was taken. T is the time from starting the sedimentation until taking the readings. At the same time, k is constant based on the solution temperature degree and the biosolid particles' definite gravity. Values of K were taken from the table included in appendix 1: (Soil, Rock. Subcommittee D18. 03 on Texture et al. 2007).

(c) Chemical Analysis

A. Determination of pH Value

The materials and apparatus used for determining the pH value include; a pH meter, balance, graduated cylinder, glass beaker 100ml, glass rod, and plastic bottle. The procedure involved weighing 10g of the received sample, putting it in a plastic bottle, then adding 50ml of distilled water in the ratio of 1:5 and mixing it well using a glass rod. The mixture was then left to settle for half an hour while stirring the suspension every 10 minutes during this phase. An hour later, the suspension was stirred again before inserting the combined electrode, 3cm deep into the suspension, and readings were recorded after 30 seconds. After that, the electrode was removed from the suspension, cleaned using distilled water in a different beaker, and the excess water dried off with tissue paper (ASTM 2006).

B. Determination of Electrical conductivity EC (mS/cm).

The materials and apparatus used for this test included a conductivity meter, balance, graduated cylinder, plastic bottle, thermometer, and glass rod. The procedure involved preparing a 1:5 (w/v) water suspension sample. The pH was determined by mixing the sample well using a glass rod and allowing it to settle for half an hour. The suspension was continuously stirred after every 10 minutes during this stage, as in the previous process. After one hour, the suspension was stirred again before immersing the conductivity cell into the suspension and the readings are taken. The conductivity cell was removed, cleaned scrupulously with distilled water, and let to dry. The EC measurements were taken at 25^{o}C, and the EC meter was corrected by multiplying it with the appropriate factor from the table in appendix 2 by using the formulae below (ASTM 2006).

$$EC_{25} = EC_t * ft$$

C. Sodium Adsorption Ratio (SAR) (Soils)

The USDA Handbook No. 60 prescribes a reliable methodology for determining Sodium Adsorption Ratio (SAR) (Richards 1954). The main step in determining SAR was preparing a saturated paste by placing 100-200g (< 2mm) of air-dried biosolid samples in a plastic container, then slowly adding distilled water. This was then mixed with a spatula until the paste started to glisten as it reflect light and flowed slightly when the plastic container was tipped to slide off the spatula. The paste was left to settle for one hour before checking the criteria of saturation by adding more water or biosolid accordingly while recording the volume of water added. Sodium Portion was calculated using the equation:

SP = 100 * (total weight of water) / (total weight of oven-dry soil)

The prepared paste was left to stand for 24 hours, thereafter filtered by using suctions. The ICP-OES analyzed the filtrate for Sodium (Na), Calcium (Ca) and Magnesium (Mg). The results of Ca, Na, and Mg in the saturated extract were used to determine SAR, which was calculated as:

$$SAR = \frac{Na(Meq/L)}{\sqrt{\frac{Ca\,(Meq/l)+Mg(Meq/L)}{2}}}$$

D. Determination of exchangeable sodium percentage % (Rayment and Lyons 2011)

The exchangeable sodium percentage was determined using an extract solution of 1 M Ammonium chloride at ph. 7.0. The extract was prepared by adding 53.5 g of ammonium chloride in deionized water and diluting it to 0.9 L. Subsequently, it was adjusted to a pH of 7.0 using ammonium hydroxide and finally diluting it to 1.0 L. The procedure of determining the percentage of exchangeable Sodium started with weighing 5.00 g of air-dried biosolid (<2mm) and putting it in a 250 ml plastic extracting bottle. A 100ml of NH4CL at pH 7.0 of the extracting solution was added. The mixture was mechanically shaken at 25 C for an hour followed by centrifugation and then retained clarified extracts were prepared for analysis. The determination process made use of the ICAP spectrophotometer, and the exchangeable Sodium was expressed on a cmol/kg oven-dry basis. Cmol/Kg = meq/100g. The following equation was applied to calculate exchangeable Sodium:

Exchangeable Sodium = (concentration of Sodium in meq/L x 10) / weight of sample (g)

E. Determination of Nitrate (PPM)

The US EPA 821 METHOD 1685 was the applicable method in this process (Nelson 2003). The process of determining nitrate started by weighing 5 g of biosolid sample and placing it into Erlenmeyer flask of 250 ml and then adding 100 ml of purified water. The mixture was shaken using a mechanical shaker for four hours. After the solid have been settled, a filtrate was extracted by filtering the mixture using a 0.45-micron membrane filter. The filtrate was used to determine nitrate content using the HACH nitrate reagent. The following computation was used:

$$NO_3 \text{ (mg/Kg)} = (Cs * 100/ Wt) * 4.43$$

Whereas Cs = concentration in spectrophotometer and Wt = weight of the sample (5g)

F. Determination of Chloride content % (Richards 1954)

The materials and apparatus used in this procedure included pipette 5-25 ml, Erlenmeyer flask of 100 ml, and burette. The chemical reagent of a 5% potassium chromate solution was also used in this process. The solution was prepared by using distilled water to dissolve 5g of potassium chromate (K2CrO4). 0.01 N silver nitrate solution was added till a slight permanent red precipitate was produced. The end-solution was filtered and diluted to 100ml. The procedure also involved preparing a 0.1 N solution of silver nitrate by dissolving 16.96 gm of dry $AgNO_3$ (dried for 2 hours at 105° C) with distilled water and diluting it to one liter. The working procedure started by pipetting 10ml of suitable aliquot into a 100ml Erlenmeyer flask. 2-4 drops of 5 % potassium chromate were added and titrated with silver nitrate 0.1 N until the first reddish-brown color was observed. This was followed by reporting in meq/l to the nearest 0.1. The calculation method used to determine chloride content applied the following formula:

$$\text{Meq/L (Cl)} = \frac{dyml\ of\ AgNO3\ *\ 0.1 *1000}{ml\ of\ aliquot}$$

ppm (Cl) = Meq / L * 35.5

G. Determination of Free Carbonate (Manual of laboratory routine analysis for soil testing 1998).

The samples were analyzed using different materials and apparatus such as a 250ml Erlenmeyer flask, a 10ml pipette, a 20 ml burette, and a balance. The process included preparing three chemical reagents of ammonium oxalate, sulfuric acid 20%, and potassium permanganate 0.1 N. Ammonium oxalate was prepared by dissolving 12.4g of ammonium oxalate with distilled water while using NaOH solution to adjust the pH reading to 8.3. The solution was then diluted to one liter. Similarly, the sulfuric acid 20% was prepared by adding distilled water to 120ml of concentrated H2SO4 up to one liter, while the potassium permanganate 0.1 N was done by adding 3.16g of potassium permanganate to one liter. The working procedure for this stage involved weighing 10g of oven-dried biosolid and putting it in an Erlenmeyer flask of 250ml, then adding 250ml of ammonium oxalate 0.1 N as V1. The mixture was shaken for two hours before filtering it. A 10 ml volume of the filtrate was taken as V2, and 10 ml of sulfuric acid 20% was added before subjecting the extract to the heat of 60 – 70 ^{o}C for 10 minutes. The extract was titrated using potassium permanganate 0.1 N until the color of the solution changed to violet, and the readings for volume N were recorded. The percentage of free carbonate was calculated as illustrated below:

1 ml of potassium permanganate 0.1 N = 0.1 Meq $CaCO_3$.

= 0.1 Meq Ammonium Oxalate 0.1N.

= 0.005 g $CaCO_3$.

$$\text{Active } CaCO_3\ (\%) = \frac{(N-n) * 0.005 * V1 * 100}{V2 * wt.of\ soil}$$

H. Determination of Organic Matter Percentage % in Biosoild (Richards, 1954)

The percentage of organic matter in biosolid was determined using the following laboratory apparatus; a balance, volumetric flask, pipette, Erlenmeyer flask, and a graduated cylinder. The procedure involved preparing K-dichromate ($K_2Cr_2O_7$) 1N by dissolving 49.04g of K-dichromate in a one-liter volumetric flask with distilled water and diluting it to the mark. Similarly, 14.85 gm of Phenanthroline monohydrate and 6.95 gm ferrous sulfate were dissolved in distilled water and diluted to one liter to prepare Ortho-Phenanthroline - ferrous sulfate complex indicator (Ferroin indicator) 0.025M. The process also involved preparing $FeSO_4$ 0.5N by dissolving 140g of $FeSO_4$ in 700ml of distilled water, then transferring it to a one-liter volumetric flask. 15ml of concentrated H_2SO_4 was added to this solution and diluted to the volume. 1 g of the biosolid was weighed and transferred into a 500ml Erlenmeyer flask before adding 10ml of 1N $K_2Cr_2O_7$, then constantly and gently swirling the flask to dissolve the soil in the solution. 20ml of concentrated H_2SO_4 was added into the suspension, and again gently swirling the flask for one minute until the reagents and the soil was mixed. The mixture was allowed to stand for about 30 minutes. An addition of 200 ml of distilled water was added to the flask then ten drops of the indicator were dropped into the solution. The solution was then titrated with 0.5 N $FeSO4$ until the color changed from green to red. The organic matter percentage was calculated as follows:

$$\text{O.M. \%} = \frac{(Meq\ K2Cr2O7 - Meq\ FeSO4\,)}{O.D.Wt.Of\ soil\ (g)} * 0.336 * 1.724 \qquad \text{(Meq = volume * normality)}$$

$$\text{Organic carbon \%} = \frac{(Meq\ K2Cr2O7 - Meq\ FeSO4\,)}{O.D.Wt.Of\ soil\ (g)} * 0.336$$

I. Determination of Total Nitrogen mg/kg. (Rayment and Lyons 2011)

The semi micro-Kjeldahl Method was used to determine the total Nitrogen. The method used required the following apparatus; 100 ml micro Kjeldahl digestion flask, stand and distillation apparatus, a balance, Erlenmeyer flask, burette, electric digester, and fume hood. This assessment could have incorporated different methodologies. The procedure also included many reagents such as the digested acid of sulfuric acid (H2SO4; 18 M) and the Kjeldahl catalyst tablets, which included 1g of anhydrous sodium sulfate (Na2SO4) and 0.1 g of anhydrous copper sulfate (CUSO4). The other prepared reagent was 60% sodium hydroxide solution which was made by using deionized water to dissolve 600 g of NaOH then allowed to be cool before diluting it to one liter. Another reagent used in this process included 2% boric acid solution H3BO3, which was obtained by dissolving 80gram boric acid in three liters of water. An extra liter of water was added to the solution up to four liters, and the pH was adjusted to 5.0 by diluting it with NaOH. In addition to these reagents was a chemical indicator – Bromocresol green-methyl red – prepared by mixing five constituents; 0.1% of the green indicator $C_{12}H_{14}Br_4O_5S$ dissolved in 95% ethanol C2H5OH with one part 0.1% of methyl red C15H15N3O2 in 95% C_2H_5OH until a neutral grey color was observed.

The procedure in this process involved preparing 0.01M of hydrochloric acid by diluting 20ml of HCL, 1001M with deionized water, and diluting it to 20 liters. This made it of comparable standard to sodium tetraborate $Na_2B_4O_7.10H_2O$, which was kept in a desiccator over-saturated NaCl and sucrose for a day. 0.9535 grams of $Na_2B_4O_7.10H_2O$ was dissolved in carbon dioxide-free water up to 500ml. The procedure was summed up by titrating a 25ml aliquot with 0.01 M of hydrochloric acid using the prepared indicator. The equation below was used for calculating the HCl molarity:

$$\text{Molarity of Hydrochloric acid} = \left(\frac{g\ of\ Na2B4O7.10H2O\ in\ 500\ ml}{190.69} * \frac{Aliquot}{500} * \frac{1000}{Titre}\right)$$

Determining the total Nitrogen involved digesting and distilling each biosolid sample using the micro Kjeldahl distillation apparatus. 1 g of grounded biosolid sample of up to less than 0.5mm was put into the digestion flask and swirled gently with 2 ml of deionized water for a few minutes. It was then left to stand for half an hour. The process continued by adding two catalyst tablets and 6.5 ml of the digesting acid H_2SO_4 into the solution, then heating the flask connected to a fume remover until the water evaporated and the frothing was eliminated. The digestion process was done by subjecting the solution to more heat until the sulfuric acid condensed most of the digestion flask's content. When the biosolid began to bleach, it signaled another two more hours of boiling, after which the content was left to cool to complete the digestion process. 30ml of deionized water was added to contents while gently swirling it to stop the calcification of the digested solution as it cooled. A 10ml of 2% boric acid solution was added to the flask before placing it below the condenser opening and directly under the surface of the Boric acid solution. A 30ml of 60% Sodium Hydroxide was gently and carefully added to the flask before connecting it to the distilling apparatus. The brown precipitate of FE(OH)3 indicated that the solution became alkaline. The distillation process progressed for the next five minutes, with a distillation quantity of 8 ml per minute until the collection of a minimum of 30 ml is attained.

After that, the flask was lowered, and the deionized water was used to rinse the condenser end. The distillation process ended when the flask was removed from the heat source besides the heat not being able to surpass the 40 C mark to minimize the chances of losing the Nitrogen in the form of ammonia gas. Five drops of the indication mixture were added to the extract, and the distillate was titrated with 0.01 M of hydrochloric acid, resulting in a pH of 5.0. The calculation for determining the total nitrogen percentage was based on 1 gram of air-dried sample of biosolid and 0.01 M of Hydrochloric acid on the total digest using the following formula:

Total Biosolid Nitrogen % = [(sample titre – blank titre”) * 0.014].

J. Determination of the Available Zinc (Rayment and Lyons 2011)

The 12A1 DTPA-extractable Cu, Zn, Mn, and Fe was the most appropriate method used in this analysis. Determining the available Zinc in the soil involved the preparation of diethylene triamine Penta acetic acid solution (DTPA). Each reagent was prepared separately by dissolving it in deionized water and combining them. The 1.0-liter solution was prepared by weighing 1.97g of DTPA solution, 1.47g $CaCl_2.2H_2O$, and 14.92g of triethanolamine with 99% purity. 6.8g of hydrochloric acid was added to the mixture and diluted to 990ml with deionized water while using triethanolamine to adjust the pH to 7.3 ± 0.05. The mixture was then stored in a low-density polyethylene container and kept cool at 4°C and away from direct sunlight. The procedure also involved preparing a blank reagent without any biosolid with each batch of biosolid samples being weighed to 25g and put into a polyethylene bottle. 50 DTPA was added to the extracted solution, sealed with a stopper, and mechanically shook for two hours using a Whatman filter No. 42. A filtrate was extracted after the shaken mixture was allowed to settle. The process was completed by measuring the zinc concentration in the filtrate by ICP-OES spectrophotometer machine.

K. Determination of the Available Phosphate as PO4-P (mg/kg). (Sims 2000)

The process of determining the available phosphate used the Olsen Method, which involved preparing two key groups of chemical reagents. Group A was prepared by weighing 12.0g and 6.0g of ammonium molybdate, then dissolving them in 250ml and 125ml of distilled water, respectively. Similarly, potassium tartrate was prepared by weighing 0.291g and 0.1455g, then dissolving them in 100ml and 50ml of distilled water, respectively. These solutions were added to 1000ml of sulfuric acid 2.5M (148 ml/L), then mixed and diluted to 2.0 liters for the first concentration. Similarly, the same procedure was followed for the second mixture, which was diluted to 1.0 Liter. All were stored in a Pyrex glass bottle in a cool and dark place.

Reagents of Group B were prepared by dissolving 2.639g of ascorbic acid in 500ml of Reagent A. The reagent was used within or less than 24 hours after preparation. 0.5 M NaHCO3 (pH 8.5) extracting solution was prepared by dissolving 420g commercial-grade sodium bicarbonate in distilled water, and the volume diluted to 10 liters. The NaHCO3 was dissolved by using an electric mixer, and its pH attuned to 8.5 using 50% sodium hydroxide. The methodology used in this determination process involved weighing 1 g of the biosolid sample and adding it in a 250ml Erlenmeyer flask, then adding 20ml of extracting solution. The mixture is then mechanically shaken for half an hour before filtering it through a Whatman filter No.40. A 5.0 ml volume of aliquot was taken and put in a 50ml volumetric flask, then another

5.0ml of Reagent B was added with 15 ml of distilled water. The mixture was left to stand for ten minutes until the color was observed before the analysis. The mixture was analyzed using HACH DR 5000 spectrophotometer by taking 5.0ml extracting solution as blank and doing all the procedures the same as the sample. Calculation of phosphate concentration was done as follows:

P = P mg/L X 20

L. Determination of Total Phosphorus and Heavy Metals by US EPA Method 6010C/3051 (Broz 2017) (Element 2007).

The samples were first prepared using a microwave oven. 0.5 g of the soil sample was extracted and dissolved in concentrated nitric acid, or concentrated nitric acid and concentrated hydrochloric acid under microwave heating with an appropriate laboratory microwave unit. Both the acid (s) and the sample were put in vessel liner or fluorocarbon polymer (PFA or TFM) or quartz microwave vessel. The vessel was vacuum-packed and heated for a specified time in the microwave unit. The vessel was then cooled and its contents filtered, centrifuged then diluted to volume for chemical analysis using ICP-OES (Inductively coupled Plasma-Optical emission spectrometry). In summary of the ICP-OES method, before the chemical analysis, the appropriate sample preparation methods were used to digest the samples (Broz 2017). In this case, a microwave digestion procedure was conducted for soil samples. The heavy metals concentration in the collected samples was detected after the biosolid samples were weighed (0.31 to 0.37 g) and digested in a microwave oven and after that diluted with 50ml ultrapure water. The samples were filtered using fiber filter paper before using the ICP-OES (Inductively coupled plasma-optical emission spectrometer) to analyze them. This approach used sequential or simultaneous optical systems and axial or radial viewing of the plasma to describe the multi-elemental determinations by ICP-OES. The instrument used optical spectrometry to measure the characteristic emission spectra. The samples were nebulized, and the resultant aerosol was moved to the plasma torch. A radio-frequency inductively coupled plasma produced element-specific emission spectra. A grating spectrometer disperses the spectra, and photosensitive devices monitor the intensities of the emission lines. Background correction is required for trace element determination. During the analysis, background emission needs to be determined adjacent to the analytic line on the samples. The complexity of the spectrum adjacent to the analytic line, on either or both sides of the line, helped to determine the position for measuring the background intensity. The selected position must be free from any spectral interference and must reflect similar changes in background intensity as it occurred when the analytic wavelength was determined. In the case of line broadening, background correction was irrelevant as it would degrade the analytical results. This method allowed for the detection of the total phosphorus and heavy metals concentration mg/kg, as well as the analysis of the detected total phosphorus, Boron B, Potassium K, Manganese Mn, Magnesium Mg, Calcium, Ca, and Iron Fe.

2. Experiment No. 2

Treatment No. 1:

The treatment consisted of 5kg of biosolid class A and dune sand only. Samples of biosolids were randomly collected in sealed bags of 10kg from freshly produced sludge from the Doha North Sewage Treatment Plant [DNSTP]. The dune sand was brought from the only source approved by Qatar’s Ministry of Municipality and Environment [MME]. The 5kg of biosolids were mixed into a homogenized mixture with dune sand in a standard square wooden frame of a one-meter square and a soil thickness of 15cm for the proper imitation of mixing depth of biosolids in landscaping projects. Permanent markers marked the filled pots before planting them with Petunia atkinsiana.

Treatment No. 2

The soil of this treatment consisted of dune sand only as a control treatment. The dune sand was brought from the same approved source mentioned. The same batch, pot size, and biological indicator plants as in the first treatment were used in this experiment as well. Also, four replicates were similarly prepared, filled, and planted similarly as in Treatment No. 1

Treatment No. 3

The mixture used comprised of dune sand and chemical fertilizer dosages of NPK and other macro elements as specified and used by the local company of Al Sulaiteen Group. This company is the major producer of Petunia plants in Qatar. Four replicates of standard pots size of 24cm were filled from the same batch of dune sand brought from the approved government source in the Ministry of Municipality and Environment, then planted with Petunia atkinsiana plants. This treatment was subjected to an intensive chemical fertilizing program used by the commercial producer for each growth stage as follows:

Stage 1 (four leaves stage):

The chemical fertilizers applied for this stage were added with the irrigation water and contained water-soluble Calcium nitrate in the first week. This was alternated in the second week with NPK 20:20:20 and microelements with a concentration of 0.2

– 0.50 gm per liter of water.

Stage 2 (eight to ten leaves stage):

The chemical fertilizers applied for this second stage comprised of Potassium nitrate, NPK 12:12:36 with microelements, and NPK 20:20:20 with Microelements, which was used alternatively with a frequency of one dosage in every four days with a concentration of 0.5 – 0.6 gm per liter of water.

Stage 3 (After emerging the first flower):

The same chemical fertilizer combination used in the second stage was replicated in this stage.

For all the above stages, the producer recommended an additional 2g per liter of Fe chelate whenever required based on plant conditions. Similarly, Magnesium sulfate was proposed in a smaller amount of 0.5g per liter at the early Stage No. 1. The application of all fertilizers and the recommended dosages were carefully done over the whole experiment period.

Treatment No. 4:

The mixture used here simulated the actual soil texture as commonly used by MME in its landscaping projects. It consisted of dune sand, soil additives of 5kg heat-treated organic manure, and 20liter of peat moss per square meter. The dune sand, from the same government-approved source, was mixed with all other ingredients in the standard wooden frame of one square meter. The mixing process was prepared for the depth of 15cm as specified in QCS. Four different replicates were prepared by filling the 24cm diameter pots then planting with Petunia atkinsiana plants. All pots were placed in the greenhouse and subjected to the same environmental conditions, daily irrigation rates, and careful monitoring within three months of follow-up. Growth parameters of plants such as the height, stem caliper, number of leaves, leaf width, leaf length, the number of flowers and plants, dry-matter percentage were measured and recorded using standard measures like standard tape measure and digital Vernier caliper. All the results were subjected to statistical analysis. The soil mixture in all treatments received the following laboratory chemical analysis.

(a) Chemical Analysis

A. Determination of Soil pH: (ASTM C136-06 2006)

The following materials and apparatus were used to determine the soil pH: pH Meter, balance, graduated cylinder, glass beaker 100ml, glass rod, and plastic bottle. The procedure involved weighing 10 g of the received sample and putting it in the plastic bottle, then a 50ml of deionized water (1:5) was added. A glass rod was used to mix the mixture before allowing it to settle for half an hour while stirring it every 10 minutes. This was followed by another stirring after an hour before inserting the combined electrode, 3cm deep, into the suspension, and readings recorded after 30 seconds. After that, the electrode was ejected from the suspension, washed with distilled water in a different beaker, and the excess water dried using tissue paper.

B. Determination of Dry Matter for Petunia Plants % (Chemists 1990)

This standard test depended on using an oven to dry the sample and evaporate the moisture. The remaining dry matter was easily determined using the gravimetrical method. The procedure encompassed drying aluminum plate with cover in an oven at 135C ± 2 ^{o}C for two hours, then afterward covering the plates and moving them to a desiccator and left to cool at room temperature. The plates were weighed with covers and removed one after another. The plant samples were later added and weighed with cover. The sample with the plate without covers was inserted in the preheated oven at 135C for another two hours. The plates were moved along with putting covers, then immediately sealed and left at room temperature to cool again before weighing them with cover and the readings were recorded. The following equation was used to calculate the dry matter:

$$\text{Total Dry Matter DM \%} = \frac{W6 - W4}{W5 - W4} * 100$$

Where W_4 is the weight of the plate in grams, while W_5 is the weight of the sample and dish in grams before drying, and lastly, W_6 is the dry weight of the plate and sample. Similarly, the total moisture percentage was determined by applying the following equation:

Total moisture % = 100 – Total Dry Matter %

C. Determination of Electrical Conductivity EC (mS/cm). (ASTM C136-06 2006)

In this test the same methodology as in experiment no. 1 was followed to determine the electrical conductivity by using the same materials and apparatus. The EC measurements were done at 25°C, and the EC meter was corrected by multiplying it with the appropriate factor from Appendix 2.

D. Sodium Adsorption Ratio (SAR) (Soils)

The Sodium adsorption ratio was determined with a basis to the USDA

Handbook No.60. The Same methodology as in experiment no.1 was followed to specify the same parameter with the same calculation formulae:

SP = 100 * (total weight of water) / (total weight of oven-dry soil)

The prepared paste was left to stand over 24 hours and filtered by using suctions. The filtrate was analyzed using ICP-OES for Sodium Na, Calcium Ca, and Magnesium Mg. The results of Ca, Na, and Mg in the saturated extract were used to determine SAR using the formula;

$$SAR = \frac{Na(Meq/L)}{\sqrt{\frac{Ca\,(Meq/l)+Mg(Meq/L)}{2}}}$$

E. Determination of Exchangeable Sodium Percentage % (Rayment and Lyons 2011)

The process used 15A1- 1 M ammonium chloride pH7.0, with no pretreatment of salt. The chemical analysis for this case involved following a similar procedure as highlighted in experiment no. 1, similary, The ICAP spectrophotometer was used to determine the exchangeable Sodium, expressed on cmol/kg oven-dry basis. Cmol/Kg = meq/100g. Exchangeable Sodium was calculated by using the following equation:

Exchangeable Sodium = (concentration of Sodium in meq/L x 10) / weight of sample (g)

F. Determination of Nitrate (PPM) (Nelson 2003)

The US EPA 821 method no. 1685 was used as in experiment no. 1, while, The calculation process involved the following equation:

NO_3 (mg/Kg) = (Cs* 100/ Wt) * 4.43

Whereas Cs = concentration in spectrophotometer and Wt = weight of the sample (5g)

G. Determination of Chloride content % (Richards 1954)

The process incorporated the same methodology as specified by Richards handbook, furthermore, The calculation method used to determine chloride content applied the following formula:

$$\text{Meq/L (Cl)} = \frac{dyml\ of\ AgNO3\ *\ 0.1 * 1000}{ml\ of\ aliquot}$$

$$\text{ppm (Cl)} = \text{Meq / L} * 35.5\ .$$

H. Determination of Free Carbonate (Manual of laboratory routine analysis for soil testing 1998).

The sample preparation along with calculation method is elaborated in experiment no. 1 for this major parameter.

I. Determination of Organic Matter Percentage % in Biosolid (Soils)

The organic matter percentage in biosolid was determined using the methodology and materials described in experiment no. 1 for the same parameters , subsequently, Organic matter percentage was calculated using the equation:

$$\text{O.M. \%} = \frac{(Meq\ K2Cr2O7 - Meq\ FeSO4\,)}{O.D.Wt.Of\ soil\ (g)} * 0.336 * 1.724$$ (Meq = volume * normality)

$$\text{Organic carbon \%} = \frac{(Meq\ K2Cr2O7 - Meq\ FeSO4\,)}{O.D.Wt.Of\ soil\ (g)} * 0.336$$

J. Determination of Total Nitrogen mg/kg. (Rayment and Lyons 2011)

The semi-micro Kjeldahl was the applied methodology for this analysis as detailed in experiment no. 1. This include the utilized materials and calculation method.

K. Determination of the Available Zinc (Rayment and Lyons, 2014)

The utilized method was illustrated by Rayment and Lyons. As detailed in experiment no. 1.

L. Determination of the available phosphate as PO4-P (mg/kg). (Sims 2000)

The Olsen Method took place at lab as described in Experiment no. 1. The same can be told concerning calculation of P concentration by using the following equation:

P = P mg/L X 20

M. Determination of Total Phosphorus And Heavy Metals (Nelson 2003) (Element 2007)

The digestion of samples followed (EPA, 2007). meanwhile, the detailed procedure was highlighted in experiment no.1 methods .

3. Experiment No. 3

(a) Preparations and Sampling

This experiment purposed to investigate three different application rates of class A biosolids to obtain the answers and arrive at a proper model for the ideal biosolid application rate. The biosolid rate started at 3 Kg/m^2, then moved up 5 Kg/ m^2, which is the currently used dosage by the Ministry of Municipality and environment, and finally adjusted the rates to 7 Kg/ m^2. These three concentrations represented the conceptual scenario for testing application rates, both lower and higher than the recommended dosage to specify a practical application model. This can improve the soil properties without any adverse impacts on soil and groundwater. The experiment was carried out in standard pots of a 24 cm diameter in greenhouse conditions. The biosolid samples were randomly taken from the freshly produced material from the approved treatment plant in sealed 10kg bags. The soil texture preparation for each treatment took place in the greenhouse as follows:

Treatment 1

The materials used included dune sand brought from the approved government source of the Ministry of Municipality and environment. The soil was mixed well with 3kg of biosolid class A in the standard wooden square meter with a thickness of 15cm to simulate the actual procedure followed in projects. Marked pots with permanent paint pens were filled with the specified soil of three replicates before planting them with seedling plants of *Petunia atkinsiana* as indicative plants.

Treatment 2

Preparing this soil texture included mixing dune sand with Class-A biosolid of 5 Kg/m^2 by following the same procedure as in the first treatment. This is the approved and followed dosage by the Ministry of Municipality and Environment in Qatar and specified in the latest approved version of Qatar construction specifications QCS. Three replicates were prepared, and pots filled with the mixture and planted with *Petunia atkinsiana* plants.

Treatment 3

With 7 Kg/ m^2 of biosolid and dune sand, this texture was prepared per the concept of trying a higher application rate to investigate the results. Three replicates were prepared to investigate this rate alongside planting the pots with *Petunia atkinsiana*.

Treatment 4

Control treatment of three replicates consisting of dune sand only without any additives was prepared to compare it against the remaining proposed textures. The pots were planted with unified and similar plants of *Petunia atkinsiana*. All treatment was put inside the greenhouse with similar daily irrigation figures and closely monitored. Similar biological parameters of plants were measured and recorded by using a standard measuring tape and digital Vernier caliper. The records included the stem girth, plant height, number of leaves, leaves width and length, number of flowers, and plants dry matter. The soil was subjected to chemical analysis after a period of three months, and the indicative growth parameters of plants were recorded and statistically analyzed. Also, the water leachates were gathered and analyzed to specify the potential impacts of pollutants on groundwater.

(b) Chemical Analysis

A. Determination of Dry Matter for Petunia plants % (Chemists 1990)

This standard test depended on the use of the oven to dry the sample where the moisture evaporated, and the dry matter remained to ease the process of determination using the gravimetrical method. The procedure simply involved drying the aluminum plate with cover in an oven at 135 centigrade $\pm$ 2 ^oC for a period of two hours, then covering the plates and moving it to desiccator to cool to room temperature. The plates were weighed with covers and removed one by one, then the plant sample was added and weighed with cover. The sample with the plate without covers was inserted in the preheated oven at 135 centigrade for another two hours. The plates were moved, covered, and immediately sealed, and allowed to cool to room temperature again before weighing them with cover and recording them. The following equation was used for computing total dry matter:

$$\text{Total Dry Matter DM \%} = \frac{W6 - W4}{W5 - W4} * 100$$

Where W_4 is the weight of the plate in grams, W_5 is the weight of the sample and dish in grams before drying, and lastly, W_6 is the dry weight of the plate and sample. Similarly, the total moisture percent were determined using the following equation:

Total moisture % = 100 – Total Dry Matter %

B. Determination of Soil pH (ASTM C136-06 2006)

Materials and steps are fully described in experiment no. 1.

C. Determination of Electrical conductivity EC (mS/cm). (ASTM C136-06 2006)

For the materials, apparatus and methodology, please, refer to experiment no. 1 and appendix 2.

D. Sodium Adsorption Ratio (SAR) (Soils)

(SAR) was specified in accordance with USDA Handbook No. 60. The main steps and equation of calculation are described in this chapter as in experiment no. 1.

E. Determination of exchangeable sodium percentage % (Rayment and Lyons 2011).

For the details, please, refer to experiment no. 1. On the same page, calculation was managed by using the following equation:

Exchangeable Sodium = (concentration of Sodium in meq/L x 10) / weight of sample (g)

F. Determination of Nitrate (PPM) (Nelson 2003)

The US EPA 821 method 1685 was fully Described in methods of experiment no. 1, similarly, the calculation method to specify this main parameter was detailed as well.

G. Determination of Chloride content % (Richards 1954)

The process has been followed in experiments no. 1 and 2 along with the same calculation method.

H. Determination of Free Carbonate (Manual of laboratory routine analysis for soil testing 1998)

I. For the sample preparation, materials and apparatus additional to calculation method, please, check experiment no. 1.

J. Determination of Organic Matter Percentage % in Biosolid (Richards 1954)

Please, refer to the same parameter as described in experiment no. 1.

K. Determination of Total Nitrogen mg/kg. (Rayment and Lyons 2011).

The semi-micro Kjeldahl method is fully described in experiment no. 1 in pertaining to the calculation of total nitrogen.

L. Determination of the Available Zinc (Rayment and Lyons 2011)

The method used in this test was 12A1 DTPA-extractable Cu, Zn, Mn, and Fe. as highlighted in experiment no.1 of this chapter.

M. Determination of the Available Phosphate as PO4-P (mg/kg). (Sims 2000).

The Olsen Method and calculation procedure is fully described in experiment no. 1.

N. Determination of total phosphorus and heavy metals (EPA, 2007) (Element, 2007)

The samples preparation and digestion is as per the specified method in experiment no. 1. This method allowed for the detection of the total phosphorus and heavy metals concentration mg/kg, as well as the analysis of the detected total phosphorus, Boron B, Potassium K, Manganese Mn, Magnesium Mg, Calcium, Ca, and Iron Fe.

(c) Chemical Analysis of leachate water

Different chemical analyses took place to evaluate the potential impacts of pollutants on groundwater in the future, based on the expected frequency of application rates, as well as check the differences of residuals between the tested application rates on the water by investigating the leachates. Tests were done after three months from the starting date. The biosolid pellets were melted and homogenized with the soil for the analysis process. The leachates were gathered carefully from the saucers of pots in marked plastic bottles with tight lids for analyses. All details about leachate preparation, such as the temperature during the test conduction, the volume of leachate added during extraction, the volume of the eluate filtrate, and other related information like date, type of test, and the followed procedure were recorded. (EN) (12457-1 2002). The tested parameters and methodology were as follows:

A. Determination of pH value:

The materials and apparatus used for determining the pH value include; a pH meter, balance, graduated cylinder, glass beaker 100ml, glass rod, and plastic bottle. The procedure involved weighing 10g of the received sample, putting it in a plastic bottle, then adding 50ml of distilled water in the ratio of 1:5 and mixing the mixture well using a glass rod. The mixture was then left to stand for 30 minutes while stirring the suspension every 10 minutes during this phase. An hour later, the suspension was stirred before inserting the combined electrode inserted into it for a depth of about 3cm, and readings were recorded after 30 seconds. After that, the electrode was removed from the suspension, cleaned using distilled water in a different beaker, and the excess water dried off with tissue paper (ASTM 2006).

B. Determination of Electrical conductivity EC (mS/cm).

The materials and apparatus used for this test included a conductivity meter, balance, graduated cylinder, plastic bottle, thermometer, and glass rod. The procedure involved preparing a 1:5 (w/v) water suspension sample. The pH was determined by mixing the sample well using a glass rod and allowing it to settle for half an hour. The suspension was continuously stirred after every 10 minutes during this stage, as in the previous process. After one hour, the suspension was stirred again before immersing the conductivity cell into the suspension and the readings were taken. Then, the cell was removed, cleaned scrupulously with distilled water, and let to dry. The EC measurements were taken at 25°C, and EC meter was corrected by multiplying it with the appropriate factor from appendix 2 using the formulae below (ASTM 2006).

$$EC_{25} = EC_t * ft$$

C. Sodium adsorption Ratio (SAR) (Soils)

The primary step in SAR determination involved determining the sodium, Magnesium, and Calcium in leachate samples to determine the Sodium adsorption ratio SAR.

D. Determination of Sodium in Water Leachate (water research and study center 1990).

The materials and apparatus used were pipette, volumetric flask, and a flame photometer. The process started with the preparation of Sodium standard solution 1000 ppm by dissolving 2.542gm of sodium chloride NaCl in purified water and putting it in a one-liter volumetric flask, then topping up the volume with distilled water. A series of 0, 5, 10, 15, 20, and 30 ppm of Na-standard was prepared from the solution using the pipette for 0, 5, 1.0, 1.5, 2, 3 ml in a volumetric flask and added distilled water to the top it up to volume. The procedure involved measuring standard series and samples at the flame photometer. The calculation process necessitated plotting a graph relating the part per million ppm in the pre-prepared standard series to flame photometer readings to create a linear regression.

For sodium calculation, the following equation was applied:

$$\text{Na (Meq/L)} = \frac{ppm\ (from\ the\ curve)}{Eq.Wt}$$

$$\text{Na (Meq/L)} = \text{ppm} * 0.0435$$

E. Determination Of Calcium and Magnesium In Water Leachate

The test used the following materials and apparatus: pipette 5-25ml, Erlenmeyer flask 125ml, and burette, while the used chemical reagents comprised of Sodium Hydroxide 4 N, Ammonium Purpurate Indicator, Na2-EDTA (0.01 N), NH4Cl-NH4OH buffer solution, and EBT Indicator. The determination procedure involved pipetting 5-25 ml of aliquot into a 125ml Erlenmeyer flask and diluting it to a volume of approximately 25ml. The procedure started by taking 5-25ml of an aliquot in an Erlenmeyer flask of 125 ml then diluting it to 25 ml. Five drops of 0.25ml of sodium hydroxide were added along with 4 N and approximately 50mg of ammonium purpurate indicator as well. 0.01N Na2-EDTA solution was used to titrate the mixture until the color changed from red-orange to lavender or purple to mark the endpoint. Every 5 –

10 seconds, one drop of EDTA was added. At this point, a blank including sodium hydroxide, ammonium purpurate additional to 2 drops of EDTA helped in recognizing the endpoint. The Meq/L of calcium have been reported to the nearest 0.1 and calculated as follows:

$$Ca\ (Meq/L) = \frac{vol.of\ Na2{-}EDTA\ *\ N\ *1000}{vol.of\ aliquot}$$

Ca (ppm) = mg. (Ca) /L = Meq/L * Atomic or equivalent wt. = Meq/L * 20

Similarly, determining Magnesium involved pipetting 5-25 ml of aliquot into 125 ml Erlenmeyer flask and diluting to 25 ml and then adding ten drops from buffer solution of NH4CL-NH4OH mixed with three drops of EBT indicator. 0.01 N Na2-EDTA solution was used to titrate the solution until the color changed to blue-green from wine-red with every drop of EDTA indicator, which was added every five to ten seconds. A blank including buffer solution of NH4CL-NH4OH mixed with four drops of EBT and two drops of EDTA clarified the endpoint, and the Meq/L of calcium plus magnesium was reported to the nearest 0.1. (Richards, 1954). The calculation used the following method;

$$Meq/L\ of\ (Ca+Mg) = \frac{vol.Of\ Na2{-}EDTA * N * 1000}{vol.Of\ aliquot}$$

For the calculation of magnesium only in Meq/L, it was calculated by the difference

Mg (ppm) = Meq/L * equivalent wt. = Meq/L * 12

SAR was calculated as follows:

$$SAR = \frac{Na(Meq/L)}{\sqrt{\frac{Ca\,(Meq/l)+Mg(Meq/L)}{2}}}$$

F. Determination of Exchangeable Sodium Percentage % (Rayment and Lyons 2011).

The analysis at this stage involved preparing a solution of 1 M Ammonium chloride at a pH of 7.0. The procedure involved weighing 53.5 g of ammonium chloride and mixing it in deionized water, then diluting it to 0.9L. Ammonium hydroxide was used to adjust the solution's pH to 7.0 and finally diluted to 1.0L. The determination procedure started with measuring 5.00ml of leachate water of each sample and putting it into a 250ml plastic extracting bottle. A 100ml of NH4CL at pH 7.0 of the extracting solution was added, then mechanically shaken end-over-end at 25C for an hour followed by centrifugation process and retained clarified extracts for analysis. The ICAP spectrophotometer was used in the determination process, and the exchangeable Sodium was expressed in cmol/liter. Exchangeable Sodium was calculated using the following equation:

Exchangeable Sodium = (concentration of Sodium in meq/L x 10) / measure of sample (L)

G. Determination of Nitrate mg/L (Management 1994)

The following apparatus and equipment were used to determine the nitrate in water leachate, five hundred ml Erlenmeyer flask, Mechanical shaker, filter syringe, and filtration column. These types of equipment were used for the extraction process, while the spectrophotometer was used for the analyses. Similarly, the chemical reagents were sulfanilamide and N-(1-naphthyl) ethylenediamine dihydrochloride. The procedure involved filtering the leachate samples in the flask and shaking them for four hours before passing them through the filtration column to remove the cadmium-cooper. The sample was prepared for analysis by changing any presented nitrite to nitrate in each leachate. To assess the concentration of nitrate, we diazotized the leachate with sulfanilamide followed by binding it with N-(1-naphthyl) ethylenediamine dihydrochloride to make a clear colored azo pigment. The spectrophotometer measured the nitrate concentration. A comparison was made between the absorbance record for the leachates and the calibration curve of the spectrophotometer. Furthermore, the concentration in mg/L was calculated by applying the following equation:

$$C_S = \frac{(C\ \text{extract})(V\ \text{sample})(R\ \text{volume})(F\ \text{dilution})}{1000\ \text{ml/L}}$$

Whereas the Cs and C extract are oxidized nitrogen in leachate and in the extract in a row reported in (mg/L), while V sample is the volume of leachate reported in 100 ml, Similarly, the R vol is the ratio of original leachate volume to the volume of filtrate gathered reported as 4:1 (100/25). Lastly, F dilution is the dilution factor of extract.

H. Determination of Sulphates Content % (Richards, 1954)

The following apparatus was used to determine the percentage of sulfates content: 20 ml pipette, 250 ml conical flask, 10 ml graduated cylinder. 10ml graduated burette every 0.1 ml. Hot plate. Ash less filter paper (Whatman No. 42), Silica crucible to (0.001g), Ignition oven without flaming (800-900 ^{o}C), and a balance. Three types of chemical reagents were prepared and used. First was a concentrated Hydrochloric acid (sp.gr. 1.19), then 10% Barium chloride solution which was prepared by dissolving 100gm of $BaCl_2.2H_2O$ in one liter of distilled water and filtering it, and the last chemical was the Methyl orange, 0.1% which was made by diluting 10 ml of methyl orange to 100ml with distilled water. The process commenced by pipetting a 20 ml aliquot of the water sample in the conical flask of 250ml. This was followed by adding distilled water to about 100ml, then another 1 ml of concentrated HCl was added. The solution was then heated to boil on a hot plate before adding excess BaCl2 solution of about 10 ml then further heated for 10 minutes. It was then left to stand and cool for an hour at room temperature. The procedure continued by filtering it through ashless filter paper and washed with distilled water. The filter paper was cautiously folded and placed in a weighed crucible, then ignited for 30 minutes in the oven at a temperature of 800-900^{o}C before cooling the crucible in the desiccator and reweighing it. Calculations were done using the following method:

Weight of BaSO4 (gm) = wt. of the ignited crucible - wt. of the clean crucible

$$\text{SO4 (meq/L)} = \frac{\text{wt.Of BaSO4(g)}}{\text{vol.Of aliquot}} * 8568.2$$

$$\text{SO4 (ppm)} = \frac{\text{wt.Of BaSO4(g)}}{\text{vol.Of aliquot}} * 8568.2 * 40.03$$

I. Determination of Chloride Content % (Richards, 1954)

The process used the following materials and apparatus; pipette 5-25 ml, Erlenmeyer flask of 100 ml, and burette. The chemical reagent of 5% Potassium chromate solution used in this method was formed by using deionized water to dissolve 5 g of potassium chromate (K2CrO4), and a 0.01 N silver nitrate solution was added until a slight permanent red precipitate was produced. The end-solution was filtered and diluted to 100ml. The procedure also involved preparing a 0.1 N solution of silver nitrate by dissolving 16.96 gm of dry $AgNO_3$ (dried for 2 hours at 105^{o} C) with distilled water and diluting it to one liter. The working procedure started by pipetting 10ml of suitable aliquot into 100ml Erlenmeyer flask, then 2-4 drops of 5 % potassium chromate were added and titrated with silver nitrate 0.1 N until the first reddish-brown color was observed. This was followed by reporting in meq/l to the nearest 0.1. The calculation method used to determine chloride content applied the following formula:

$$\text{Meq/L (Cl)} = \frac{\text{dyml of AgNO3} * 0.1 * 1000}{\text{ml of aliquot}}$$

$$\text{Ppm (Cl)} = \text{Meq / L} * 35.5$$

J. Determination of Free Carbonate (Manual of laboratory routine analysis for soil testing 1998).

The samples were analyzed using different materials and apparatus such as a 250ml Erlenmeyer flask, a 10ml pipette, a 20ml burette, and a balance. The process included preparing three chemical reagents of Ammonium Oxalate, sulfuric acid 20%, and potassium permanganate 0.1 N. Ammonium oxalate was prepared by dissolving 12.4g of ammonium oxalate with NaOH solution to adjust the pH reading to 8.3 then diluting the mixture to one liter. Similarly, the sulfuric acid 20% was prepared by adding 120ml of concentrated H2SO4 to one liter, while the potassium permanganate 0.1 N was done by adding 3.16g of potassium permanganate to one liter. The working procedure for this stage involved weighing 10g of oven-dried biosolid and putting it in an Erlenmeyer flask of 250ml, then adding 250ml of ammonium oxalate 0.1 N as V1. The mixture was shaken for two hours before filtering it. A 10 ml volume of the filtrate was taken as V2, and 10 ml of sulfuric acid 20% added, then subjecting the extract into the heat of about 60 – 70 ^{o}C for 10 minutes. The extract was titrated using potassium permanganate 0.1 N until the color of the solution changed to violet, and after that, the readings for volume N was recorded. The percentage of free carbonate was calculated as illustrated below:

1 ml of potassium permanganate 0.1 N = 0.1 Meq $CaCO_3$.

= 0.1 Meq Ammonium Oxalate 0.1N.

= 0.005 g $CaCO_3$.

$$\text{Active } CaCO_3\ (\%) = \frac{(N-n) * 0.005 * V1 * 100}{V2 * \text{wt.of soil}}$$

K. Determination of Organic Matter Percentage % in Biosolid (Richards 1954)

The percentage of organic matter in biosolid in the laboratory was determined using apparatus, including a balance, volumetric flask, pipette, Erlenmeyer flask, and graduate cylinder. The analysis started by preparing K-dichromate ($K_2Cr_2O_7$) 1N by dissolving 49.04 of K-dichromate in purified water in a one-liter volumetric flask then diluted to the mark. Similarly, 14.85gm O-Phenanthroline monohydrate and 6.95gm ferrous sulfate were dissolved in purified water and diluted it to one liter to prepare Ortho-Phenanthroline - ferrous sulfate complex indicator (Ferroin indicator) 0.025M. Also, $FeSO_4$ 0.5N was formed by dissolving 140g of $FeSO_4$ in 700ml of distilled water, then transferring it to a one-liter volumetric flask before adding 15ml of concentrated H_2SO_4 and diluting the solution to volume. The analysis process also incorporated weighing out 1.0g of the biosolid and transferring it into a 500ml Erlenmeyer flask, followed by adding 10ml of 1N $K_2Cr_2O_7$, then gently and constantly swirling the flask to disperse the soil in solution. The next stage involved adding 20ml of concentrated H_2SO_4 into the suspension, then, instantaneously swirling the flask gently until reagents and soil were mixed vigorously for one minute before leaving the flask for 30 minutes to settle. 200ml of purified water was added to the flask, followed by dripping ten drops of indicator. 0.5 N $FeSO_4$ was used to titrate the solution until the color transformed from green to red. Organic matter percentage was calculated using the equation:

$$\text{O.M. \%} = \frac{(\text{Meq K2Cr2O7} - \text{Meq FeSO4})}{\text{O.D.Wt.Of soil (g)}} * 0.336 * 1.724$$ (Meq = volume * normality)

$$\text{Organic carbon \%} = \frac{(\text{Meq K2Cr2O7} - \text{Meq FeSO4})}{\text{O.D.Wt.Of soil (g)}} * 0.336$$

L. Determination of Leachates Total Nitrogen (German Standard Method for the examination of water April 1992), (AOAC Official Method 973.48 1973), Reference for leaching (12457-1 2002)

This method differed from that used for biosolid or soil. It comprised of several steps which started by obtaining the filtrate of leachate samples of at least 2 liters. A 100ml was measured and put into a 500 ml extraction bottle, then adding 350 ml of D. W. and shaking for 24 hours using a mechanical shaker before allowing it to settle for 20 minutes. The eluate was then filtered with a filter of 0.45 μm membrane by a pressurized vacuum filter device. The filtrate was collected for the determination of total nitrogen. The procedure included pipetting the well-mixed leachate samples of 500ml with a range of concentration <1 m/L into the digestion tube along with the following additives: 5 gm of Potassium sulfate, 0.5 g of Copper sulfate, 0.2 g of Devarda's alloy, and 10 ml of H_2SO_4 98 % with a density of 1.84 gram/ml. The digestion procedure started by dehydrating leachate samples while carefully monitoring the boiling of the sample. Because of the organic content, the sample color started to change to black and formed white steam, which was eliminated after 40 minutes before the solution turned colorless followed by a light green appearance. The solution was further heated for another 10 minutes until the digestion process was completed. The distillation process started right after and involved putting the sample tube into the distillation apparatus with the 300 ml Erlenmeyer flask sized and 70 ml of boric acid used as the receiver. The sample tubing release end was put into the indicative boric acid mixture, and the NaOH was added during the process until 100ml was distilled. The outputs have been titrated together with 0.02 sulfuric acid until we reached the final stage to calculate the total nitrogen. The calculation process made use of the below methodology:

$$TN\ (mg/L) = (A-B) * 280 / \text{volume of sample}$$

Whereas A is the volume of H_2SO_4 used with the sample, and B represents the volume of H_2SO_4 used for the blank test.

M. Determination of Total Phosphorus And Heavy Metals (Broz 2017) (Symbol 2007) (Element 2007)

The samples for this analysis were prepared first by using the microwave-heating method. A representative sample of the leachate of 100ml was extracted and dissolved in concentrated nitric acid, or concentrated nitric acid and concentrated hydrochloric acid under microwave heating with an appropriate laboratory microwave unit. Both the acid (s) and the sample were put in a vessel liner or fluorocarbon polymer (PFA or TFM) or quartz microwave vessel. The vessel was vacuum-packed and heated for a specified time in the microwave unit. The vessel was then cooled and its contents filtered, centrifuged then diluted to volume for chemical analysis using ICP-OES (Inductively coupled Plasma-Optical emission spectrometry). In summary of the ICP-OES method, before the chemical analysis, the appropriate sample preparation methods were used to digest the samples (EPA, 2007). In this case, the leachate samples were digested using the microwave digestion procedure. The heavy metals concentration in the collected samples was detected using weighed leachate samples of 100 ml were measured and digested in a microwave oven then diluted with 50ml ultrapure water.

The samples were filtered using fiber filter paper before using the ICP-OES (Inductively coupled plasma-optical emission spectrometer) to analyze them. This approach used sequential or simultaneous optical systems and axial or radial viewing of the plasma to describe the multi-elemental determinations by ICP-OES. The instrument used optical spectrometry to measure the characteristic emission spectra. The samples were nebulized, and the resultant aerosol was moved to the plasma torch. A radio-frequency inductively coupled plasma produced element-specific emission spectra. A grating spectrometer disperses the spectra, and photosensitive devices monitor the intensities of the emission lines. Background correction is required for trace element determination. During the analysis, background emission needs to be determined adjacent to the analytic line on the samples. The complexity of the spectrum adjacent to the analytic line, on either or both sides of the line, helped to determine the position for measuring the background intensity. The selected position must be free from any spectral interference and must reflect similar changes in background intensity as it occurred when the analytic wavelength was determined. In the case of line broadening, background correction was irrelevant as it would degrade the analytical results. This method allowed for the detection of the total phosphorus and heavy metals concentration mg/kg, as well as the analysis of the detected total phosphorus, Boron B, Potassium K, Manganese Mn, Magnesium Mg, Calcium, Ca, and Iron Fe.

4. **Experiment No. 4 Investigating The Effects Of Using Different Biosolids Rates On Fertilizing Tomato Plant *Solanum Lycopersicum L.* And The Type of Residuals in Plants.**

(a) Preparations & Sampling

The following three treatments were prepared for this experiment.

Treatment no.1

The soil texture used in this treatment consisted of dune sand, which was brought from the approved government source of the Ministry of Municipality and Environment. The sand was sieved and cleaned to remove any undesired material or masses, before washing it with fresh water to leach salts. The sand was first left to dry before mixing it with other additives. In addition to the dune sand, Treatment No.1 also included the rate of 5kg per square meter of class A biosolid as the recommended rate by QCS Section 28(Authority, 2018). The texture and additives were well mixed to ensure that the additive and soil were homogenized before filling the pots of 40-liter size with the prepared soil texture. All replicates were planted with unified and similar-sized, healthy plants of the tomato plant (*Solanum Lycopersicum L.*) which were carefully placed in the greenhouse conditions in the Qatar Foundation's nursery for more than three months. Plant growth alongside irrigation rates was closely monitored and recorded amid other treatments. When plants started fruiting, the pots with plants and fruits were moved to the laboratory for chemical analysis.

Treatment No. 2

A similar procedure was adopted for Treatment No.2 with a different rate of 7 kg per square meter of class A biosolid. The dune sand from the same batch was used and mixed well before filling the pots of 40-liter size with the prepared soil, and similar tomato plants were planted in each pot on the same day. Similarly, the plants were moved after fruiting to the laboratory for chemical analysis.

Treatment No.3

This treatment was the control experiment used to produce tomatoes regularly. The soil texture consisted of substrate peat moss used for the production of tomatoes in Qatar. Replicates were prepared accordingly in the greenhouse with a similar procedure without any other additive of biosolid. After fruiting, all replicates were moved to the laboratory for analysis.

(b) Biological Parameters

An ideal comparison of the three different treatments necessitated consideration of the nutrient concentration within the plant. The experiment included investigating and recording the growth of biological parameters to assess the effect of nutrients on plant growth like Stem girth, the height of plants, leaf width, and length, number of leaves, and density of fruits produced for each treatment. All recorded data were subjected to statistical analysis for a better assessment of the potential impacts of biosolids on tomato growth. Also, plants have been prepared carefully for the chemical analysis, as described below.

(c) Sample Preparation For Analysis (Ryan, Garabet et al. 1996).

The preparation of plants and fruits samples took place in the laboratory by taking several steps like cleaning the plant tissue and removing the pesticide, dust, and fertilizer residues by using deionized water to wash the plants or using 0.1-0.3% P-free detergent then water for cleaning. This step was followed by stopping enzymatic activity by drying in an oven at 65^{o}C for 24 hours. After that, plant tissues were mechanically ground to produce a material appropriate for the assessment – prepared sizes were passed over a 60 mesh sieve was used. The final drying of the ground tissue happened at a temperature of 65^{o}C to obtain a constant weight.

(d) Chemical Analysis for Tomato Plants

The following analysis was used to get a sufficient and accurate assessment of the nutrients and pollutants levels in different application rates of biosolid and the control treatment as well. The series of analyses incorporated the determination of the dry matter and moisture contents, Potassium, total nitrogen, phosphorus, and heavy metals.

A. Determination of Dry Matter for Tomato plants [*Solanum Lycopersicum L.*] (Chemists 1990).

This standard test used an oven to dry the sample and evaporate the moisture to produce dry matter suitable for analysis by the gravimetrical method. The procedure encompassed drying aluminum plate with cover in an oven at 135C ± 2 ^{o}C for a period of two hours, then afterward covering the plates and moving them to a desiccator and left it to cool to room temperature. The plates were weighed with covers and removed one after another, and then the plant samples were added and weighed with cover. The sample with the plate without covers was inserted in the preheated oven at 135C for another two hours. The plates were moved along with putting covers, then immediately sealed and left at room temperature to cool again before weighing them with cover and recording the readings. The following equation was used to calculate the dry matter:

$$\text{Total Dry Matter DM \%} = \frac{W6 - W4}{W5 - W4} * 100$$

Where W_4 is the weight of the plate in grams, W_5 is the weight of the sample and dish before drying in grams, and lastly, W_6 is the dry weight of the plate and sample. Similarly, the total moisture percentage was determined by:

Total moisture % = 100 – Total Dry Matter %

B. Determination of Total Nitrogen in Tomato Plant (Manual of laboratory routine analysis for soil testing 1998)

The materials and apparatus used for this test comprised of Micro Kjeldahl digestion flask, Micro Kjeldahl stand, Micro Kjeldahl distillation apparatus, balance, Erlenmeyer flask, burette, and electrical digester and fume hood. The chemical reagents included concentrated sulfuric acid, selenium powder, Potassium sulfate K_2SO_4, Copper sulfate $CuSo_4$. The process also incorporated the preparation of the Tcheero indicator by adding a mixture of 0.375 gm Methyl red with 0.248 gm of Methylene blue and then liquefied in 300 ml of ethyl alcohol. 40% Sodium hydroxide was prepared by using 100ml of distilled water to dissolve 40g of NaOH.s Similarly, the preparation of Boric acid indicative solution, which is mainly methyl red plus Bromo cresol green 4 %. This solution was formed by dissolving 40.0 g reagent grade boric acid (H_3BO_3) in 1L of distilled water then adding 0.013g of methyl red indicator powder and 0.0065 g of Bromo cresol green indicator powder. The mixture was shaken until indicators are entirely dissolved. Finally, the standard Hydrochloric acid 0.01 N was formed by dissolving 0.84 ml of concentrated HCl in one liter of distilled water.

The process started with mixing the sample and weighing 5 gm of O.D. in the micro Kjeldahl flask. 5 gm of a mixture of copper sulfate and potassium sulfate (2:1) was then added as well as 20ml of concentrated Sulfuric acid. The procedure continued by putting the Kjeldahl flask on the heater (digester) for 5 hours until the color started to turn colorless. The change in color signaled the completion of the digestion. The flask was allowed to cool before transferring the contents to a volumetric flask of 250 ml and topped up with distilled water to the mark. The test also required taking of 20 ml of boric acid and five drops of indicator into 100 ml Erlenmeyer flask or the receiver and placing it under condenser. 25 ml from the sample was put into the cup of the apparatus with washed with distilled water. Furthermore, 20 ml of NaOH (40 %) was put in the same way as the sample, and the color turned dark brown. Through the distillation process, the color in the receiver flask turned to green color, and the volume reached > 50 ml. The procedure was finalized by titrating with 0.01 N HCl until the green color completely disappeared. The calculation process applied the following equation:

$$N\ \% = \text{Volume of titration} * 0.01 * 0.14\ g * 100 * \frac{250}{\text{wt.g}}$$

C. Determination of Phosphorus in Tomato Plant (Ryan, Garabet et al. 1996).

The essential element in plants was determined in the laboratory by using different materials and apparatus like balance, pipette, a 100ml volumetric flask, beakers, hot plate, one-liter volumetric flask, spectrophotometer, filter paper, one hundred ml digestion flask, and electric digester and fume hood. Meanwhile, three major chemical reagents were prepared. First, Ammonium Molybdate – Ammonium Vanadate in Nitric Acid, which was produced by using 300 ml of purified water to dissolve 22.5 gm ammonium molybdate, labeled as (a) and by dissolving 1.25 gm ammonium metavanadate in 400 ml hot water, labeled as (b). The two solutions were then mixed by adding (b) into (a) in a 1L volumetric flask followed by slow adding 250 ml of HNO_3 before letting it cool to room temperature and then brought to volume. The second reagent, Phosphorus Standard Stock Solution, was produced by measuring 0.2197 grams of dried KH_2PO_4 (Potassium Dihydrogen Phosphate) and transferring it to 1 L volumetric flask before dissolving it with distilled water and bringing it to volume. This mixture contained 50 ppm P. The final chemical reagent was the working Standards, which was formed by gradually adding 1, 2,3,4, and 5 ml of 50 ppm stock solution to volumetric flasks of 100-ml to obtain 0.5,1.0,1.5,2.0, and 2.5 ppm P standard solution. The working procedure started with the digestion process for plant material as described for total nitrogen in plants, and then the plant digests were filtered with a Whatman No.1 filter paper. The smaller beaker was used to collect the filtrate. The process continued by taking 10 ml of the filtrate in a volumetric flask of 100-ml and adding 10 ml of the reagent before bringing the mixture to the mark with distilled water. This was left for half an hour for the color to develop before reading the percent transmittance at 410 nm wavelength on a spectrophotometer. For standards usage, the required P stock solution was used by adding 10 ml of the reagent before bringing it to volume with distilled water and similarly leaving it for 30 minutes. Finally, the procedure ended by plotting standards on graph paper (ppm against transmittance) and readings the unknown samples from the graph(R). The calculation applied the following equations:

$$P\ \% = \frac{R\ (ppm) * 100 * 100 * 100}{10\ 000 * W}$$

Where W is the dry plant Weight (g).

D. Determination of Potassium in Tomato Plant (Manual of laboratory routine analysis for soil testing 1998)

The materials and apparatus for this chemical analysis included balance, digestion flask of 100 ml, pipette, 50 ml, 100 ml, and 1L volumetric flask, beakers, filter paper, flame photometer, electrical and fume hood, and a funnel. In addition to the above materials, several chemical reagents were prepared and used in the analysis. Precisely, Potassium Standard Stock Solution was made by adding 1.9117 gram of potassium chloride in one liter volumetric flask and topping it up to the mark to make it 1000 ppm potassium. Consequently, the working standards were prepared by adding stock solution in a portion of 0.5,1,2,4,6, and 8 ml to 100 ml volumetric flask to obtain 5, 10, 20, 40, 60, and 80 ppm potassium standard solutions. After reagent preparation, the procedure started with digesting plant material as described for the total nitrogen test in plants, followed by using Whatman No.1 filter paper to filter the plant digest and the filtrate collected in a small beaker. The process continued by taking 5 ml of filtrate in a 50 ml volumetric flask and bringing it to mark with deionized water. The concentration of potassium was measured in the standards and plotted in a graph paper and reading the unknown samples for the graph (R). Calculation applied the following equation:

$$K\ \% = \frac{R\ (ppm) * \text{Dilution Factor}}{10\ 000}$$

E. Determination of Calcium & Magnesium in Tomato Plant (Richards, 1954)

The materials and apparatus used for this test included; balance, micro Kjeldahl digestion flask, pipette, burette, filter paper, volumetric flask, graduated cylinder, and electrical digester and fume hood. The chemical reagents used included concentrated nitric acid, concentrated hydrochloric acid, perchloric acid (62%), sodium hydroxide NaOH (4N), ammonium purpurate indicator, Na_2-EDTA (0.01N), NH4Cl –NH_4OH buffer solution, and Eriochrome Black-T (EBT) indicator. The working procedure was carried out in three main steps. First, determining calcium started by mixing the sample and weighing 1gm in the micro Kjeldahl flask before adding 5 ml of Hydrochloric acid and 30 ml of nitric acid. The flask was put on the digester at a low temperature until the volume was reduced to a minimal amount quantity, then cooled. The next step involved adding 10 ml of perchloric acid, then shaking it well before returning it to the digester for an hour, then cooling. After cooling, it was rinsed with about 50 ml of purified water and placed on the digester until the volume equaled the original volume before adding water. The solution was allowed to cool before transferring it into a volumetric flask of 250 ml then diluting to the mark. The process was followed by obtaining a filtrate by filtering the solution into another 250 ml volumetric flask and gradually pipetting 5-25 ml of the filtrate into 125 ml Erlenmeyer flask and diluting to a 25ml volume. Also, five drops of about 0.25 ml of reagents NaOH (4 N) were added, and approximately 50 mg of ammonium purpurate indicator while titrating it with 0.01N Na2-EDTA solution. Close to the endpoint, EDTA was added at a rate of one drop every 5 to 10 seconds with a blank containing NaOH, ammonium purpurate, and a drop or two of EDTA being added to distinguish the endpoint. At the endpoint, the color changed to lavender or purple from orange-red. The process was finalized by reporting Meq / L of (Ca) to the nearest 0.1.

The second major step in this test was the determination of Calcium and Magnesium. The samples were digested following similar procedures above used for calcium before pipetting 5-25 ml of the sample into an Erlenmeyer flask of 125 ml and diluting it to 25ml volume. Ten drops of about 0.5ml of reagent NH4Cl –NH4OH buffer solution and another three to four drops of EBT indicator were added to the solution, and 0.01N Na2-EDTA solution was used to titrate the mixture until the color turned to blue or green from wine red. When the reaction reached close to the endpoint, EDTA was added at a rate of about a drop every 5 – 10 seconds with the blank containing NH4Cl-NH4OH buffer solution, 3-4 drops EBT indicator, and a drop or two of EDTA aided in distinguishing the endpoint. The procedure was ended up reporting Meq/L of (Ca+Mg) to the nearest 0.1.

The calculation of Calcium was done by applying the following equation:

$$\text{Ca (Meq/L)} = \frac{\text{vol. of Na2}-\text{EDTA} * \text{N} * 1000}{\text{Vol.of aliquot}} * \frac{250}{\text{wt.of sample}}$$

Ca (ppm) = Meq /L * eq .weight = Meq /L * 20

While the calculation for Calcium and Magnesium were done as follows:

$$\text{Ca+ Mg (Meq/L)} = \frac{\text{vol.of Na2}-\text{EDTA} * \text{N} * 1000}{\text{vol.of aliquot}} * \frac{250}{\text{wt.of sample}}$$

Lastly, Magnesium in (Meq/L) was calculated by difference:

Mg (ppm) = Meq/L * eq. weight = Meq/L * 12

F. Determination of Heavy Metals In Tomato Plant (Chemists. 2003).

Different apparatus and reagents were used for this test to prepare stock solutions. In each volumetric flask, the process required dissolving the minimum amount from dissolved chemical reagent then diluting with water to the volume as illustrated in Appendix 3 (Chemists, 2003)

For the preparation of standard solutions, the process carried out included pipetting specific amounts of each solution into a volumetric flask of one liter. This is followed by adding 100 ml of hydrochloric acid and diluting it to the volume with distilled water, as illustrated in appendix 4. Table of Preparation of Standard Solutions below (Chemists, 2003).

The procedure of determining heavy metals required the use of ICP emission spectrometer analysis with parameters for forwarding power of 1.1 kilowatts, and the specified reflected power was <10 watts. Consequently, the aspiration rate was 0.85–3.5 ml per minute and the flush between test solutions was 15-45 seconds with an integration time of 1-10 seconds as illustrated in appendix 5.

For the preparation of dry ashing, 1g of the testing portion was weighed, dried, and ground into a porcelain plate. The contents were dried to ash for two hours at 500C and left to cool. After that, the ash was wetted with ten drops of purified water, and 4 ml of Nitric acid was gradually added. The excessive HNO_3 was evaporated at 120C hot plate before putting it back into the porcelain plate in the oven for an additional one hour at 500C and then allowed to cool. The last step before the determination was to dissolve the ash in 10 ml of hydrochloric acid (1+1) and transfer it to a volumetric flask of 50 ml, then diluting it to volume using deionized water. The process of determining each type of heavy metal was done by spectrographic analysis using an inductively coupled plasma emission spectroscope through comparison with known calibration standards as Mg/ml.

CHAPTER 3: RESULTS AND DISCUSSION

1. Experiment No. 1

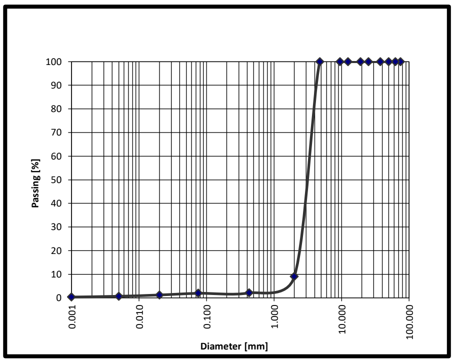
1.1.Biosolid Quality

1.1.1. Physical Characteristics

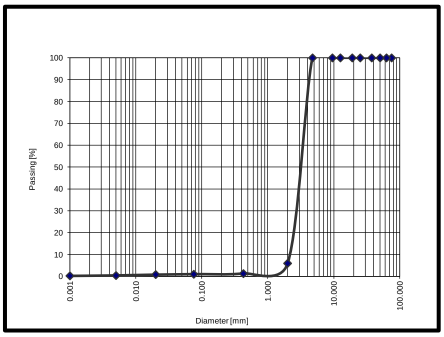
As highlighted in table 5 and the charts in figure 1, the sieving test revealed the product’s general stability concerning the particle size. 100 % of the dried pellets from all samples passed through the sieve sizes of 75, 63, 50, 37.5, 25, 19, 12.5, 9.5, 4. 75 mm in respect to the sieved particles, which complies with PWA specified standards of 75 mm. Simultaneously,93.26 % of the particles were bigger than 2mm and more diminutive than 4mm for the produced particles between 3.6 mm (Public Work Authority 2017). Meanwhile, the hydrometer analyses for particles less than 2mm reflected almost identical results, where sand particles represented 98.33 % of the total portion, and the remaining particles were silt and clay. Furthermore, a high objectionable volatile odor emanated from all samples, indicating a problem in the odor treatment unit as the odor lasted for more than a week. Such issues require insurance for public nuisance for using it as an organic fertilizer which needs to be managed by producers.

Table 5: Average Results of Sieves and Hydrometer Analysis for Bio-solid's Particles

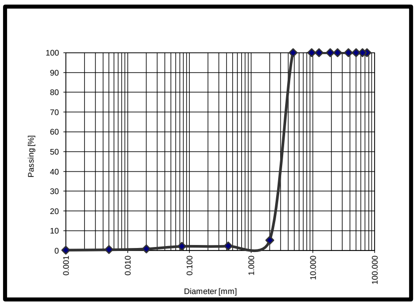
Sieve Analysis mean for samples 1		**Sieve Analysis mean for samples 2**		**Sieve Analysis mean for samples 3**	
Sieve Size [mm]	**% Passing by Weight**	**Sieve Size [mm]**	**% Passing by Weight**	**Sieve Size [mm]**	**% Passing by Weight**
75.0	100.0	75	100	75	100
63.0	100.0	63	100	63	100
50.0	100.0	50	100	50	100
37.5	100.0	37.5	100	37.5	100
25.0	100.0	25	100	25	100
19.0	100.0	19	100	19	100
12.5	100.0	12.5	100	12.5	100
9.5	100.0	9.5	100	9.5	100
4.75	100.0	4.75	100	4.75	100
2.00	9.0	2	6.0	2	5.2
0.425	2.1	0.425	1.4	0.425	2.2
0.075	1.9	0.075	1.0	0.075	2.1
Hydrometer Analysis		**Hydrometer Analysis**		**Hydrometer Analysis**	
0.02	1.2	0.02	0.8	0.02	0.8
0.005	1.5	0.005	0.4	0.005	0.4
	0.0	0.001	0.2	0.001	0.2



1	SAND [4.75-0.075mm], %	98.1
2	SILT [0.075-0.005mm], %	1.2
3	CLAY [< 0.005mm], %	0.7



1	SAND [4.75-0.075mm], %	99.0
2	SILT [0.075-0.005mm], %	0.6
3	CLAY [< 0.005mm], %	0.4



1	SAND [4.75-0.075mm], %	97.9
2	SILT [0.075-0.005mm], %	1.7
3	CLAY [< 0.005mm], %	0.4

Figure 1: Graphic Chart and Contents Ratio of Particles Smaller than 2.0 mm as Specified by Hydrometer Analysis.

1.1.2. Chemical Characteristics

Chemical analysis as highlighted in Tables 2 and 3, noted significant differences for pH versus treatment at 0.004 P-value. However, the average of each sample showed an almost neutral pH higher than 6.0 with an average range between 6.32 – 6.5 and this plays a pivotal role in reducing the soil pH during cultivation (Alayu and Leta 2020). The electrical conductivity EC) also reflected highly significant differences with 0.000 P-value, which is expected since that potable water in Qatar originates from seawater's desalination rather than groundwater harvesting. The sewage water has additional input that will variate contents (Public Work Authority 2017). However, the average range between 2.40 – 4.1 (mS/cm^2) still lies within the acceptable level as per the standards of Qatar (Authority 2018). The results revealed no significant differences for the Sodium adsorption ratio (SAR) among treatment at 0.58 P-value, whereas the average range between 5.41 – 6.16 didn't show excessive concentrations, which can be toxic to plants (Schjoerring, Cakmak et al. 2019). The results recorded significant differences for exchangeable sodium levels at 0.003 P-value and a mean range of 2.43 – 10.15. Such variability in sodium levels can be attributed to the type of input which eventually specifies the biosolid quality.

It was also confirmed that all forms of nitrogen (N) are essential parameters in assessing the quality of biosolid (Jiang, Zhou et al. 2019). The results indicated significant differences for the nitrate level at 0.000 P-value, while the average range lay between 129.55 – 398.25 ppm. Moreover, the total nitrogen level indicated no significant differences among treatments with a 0.095 P-value. Similarly, the total average range of nitrogen was 53.9 mg/kg^2. This is particularly significant as biosolid can contain almost 5.5 % of Nitrogen (Public Work Authority 2017). The variation in nitrate levels can be subjected to several reasons like forming the biosolid into granulated pellets as in class A, which can influence the rate of NO3 (Du, Cao et al. 2020). Nevertheless, high levels of nitrogen forming in biosolid were reported by many studies (Zhang, Peng et al. 2019), but it was also impacted negatively by the increase of temperature (Dan, Inam et al. 2019), for that and based on the efficient thermal treatment for biosolid in the Qatar DNSTP treatment plant; hence, variations should be very much expected and can be compared against acceptable international levels to judge it finally.

The second major nutrient for the plants besides nitrogen is Phosphorus (Jiang, Zhou et al. 2019). An analysis conducted illustrated significant differences for the parameter of total phosphorus at 0.005 P-value with an average presence range of 6.44 – 29.94 mg/kg^2 The same can be told about inorganic phosphate ions (PO4), which is an important nutrient for plants as the results highlighted high significant differences among treatments at 0.000 P-value and an average presence between 158 – 199.12 mg/kg^2. Variations in levels of phosphorus forms can be accredited to the variations in sewage inputs because P is a common component in biosolid, accounting for approximately 2.2 % of its content by volume (Authority 2018). There are different primary sources of phosphates, including beverages, food residues, and detergents, which enter the sewage stream from source points (Yu, Huang et al. 2019).

Therefore, elaboration concerning the results is made more expressive when comparing it against international standards to evaluate Qatar's biosolid quality.

The significant differences continue to appear in results of organic matter (OM) content at 0.000 P-value, along with high presence levels ranging between 59.35 – 66.5 % which is a good indicator about stabilization degree of the biosolid (Masciandaro, Peruzzi et al. 2017). It also refers to the biosolid potential ability to stimulate a high diversity of microbial communities (Zornoza, Acosta et al. 2015). The highly significant differences continue to appear for other parameters like chloride level and free carbonates as well at 0.000 P-value. Such differences can be expected as Doha north sewage treatment plant DNSTP obtains the crude sludge from non-industrial and non-medical areas (Public Work Authority 2017); hence, water softener usage containing sodium chloride (NaCl) from domestic effluent accounts for much of this Cl in sewage effluent (Asche, Fontenot et al. 2013). Variations in such cases are attributed to the disparities of sludge quality entering the sewage stream from point sources. Similarly, the variability of free carbonates level should consider the fact that Qatar’s soils are predominantly calcareous where carbonates of calcium and magnesium are dominant (Al-Thani and Yasseen 2017). Subsequently, the biosolid production process requires treatment with lime ($CaCo_3$) during thickening and dewatering stages, thus potentially contributing to raising levels of free carbonates and leading to variable presence. Lastly, the total sulphate % results indicated non-significant differences at 0.726 P-value.

Table 6: Analysis of Variance for Bio-solid Chemical Parameters

SOV	DF	MS													
		pH Value	Electrical Conductivity	Sodium Adsorption Ratio (SAR)	Exchangeable Sodium	Nitrate	Chloride Content	Free Carbonates	Organic Matter	Total Nitrogen	Total Sulphate Content	Available Phosphate as PO4-P	Available Zinc	Total Phosphorus
Treatment	2	0.040 *	3.316 **	0.680	60.060 *	724 **	0.140 **	5.251**	51.783**	161	0.0004	317**	748.29 **	562 *
Error	9	0.003	0.009	1.173	4.857	2450	0.001	0.038	0.432	522	0.001	168	11.62	564
Total	11													

* = Significant Differences ** = Highly Significant Differences

Table 7: Chemical Parameters means of Bio-solid samples with standard deviation

Test	Mean 1 / samples of bio-solids taken in February 2018	Mean 2 / samples of Bio-solids taken in May 2018	Mean3 / samples of Bio-solids taken in August 2018	Standard Deviation of Means ±
pH Value	**6.32 B**	**6.32 B**	**6.5 A**	
Electrical Conductivity	**4.1 A**	**2.40 C**	**3.82 B**	**± 0.91**
Sodium Adsorption Ratio (SAR)	**5.41 A**	**6.16 A**	**6.08 A**	**± 0.41**
Exchangeable Sodium	**10.15 A**	**5.82 AB**	**2.43 B**	**± 3.86**
Nitrate	**278 B**	**398.25 A**	**129.55 C**	**± 134.59**
Chloride Content	**0.46 A**	**0.15 B**	**0.13 B**	**± 0.18**
Free Carbonates	**1.09 B**	**0.69 C**	**2.84 A**	**± 1.14**
Organic Matter	**59.35 C**	**66.50 A**	**63.59B**	**± 3.59**
Total Nitrogen	**52 A**	**54,21 A**	**55,61A**	**± 31,68**
Total Sulphate Content	**0.29 A**	**0.29 A**	**0.27 A**	**± 0.01**

Test	Mean 1 / samples of bio-solids taken in February 2018	Mean 2 / samples of Bio-solids taken in May 2018	Mean3 / samples of Bio-solids taken in August 2018	Standard Deviation of Means ±
Available Phosphate as PO4-P	**158 ^{C}**	**1721 ^{A}**	**199.12 ^{B}**	**± 890.76**
Available Zinc	**33.45 ^{C}**	**50.60 ^{B}**	**60.48 ^{A}**	**± 13.67**
Total Phosphorus	**21 ^{AB}**	**29,94 ^{A}**	**6.44 ^{B}**	**± 15,75**

- Means comparison was conducted using the Tukey test, each two means with a similar letter have no significant differences.

1.1.3. Heavy Metals (Zn, Mn, Fe, Al, As, Cu, Cd, Co, Cr, Ni, Pb, Sn, Hg)

Undesired contamination by heavy metals is the main disadvantage of using processed sewage sludge (Rao, Thomas et al. 2017). The presence of these heavy metals indicates the degree of contamination and their impact on the quality of the biosolid (Jupp, Fowler et al. 2017). Heavy metals in sewage sludge cause various challenges and limitations where high temperatures in the production process of biosolids lead to the redistribution of heavy metals in sewage sludge through the formation of several different chemical and physical phases (Alvarez-Campos 2019) . The redistribution of heavy metals depends on the characteristics of the sewage sludge, the applied thermal process, and the operating conditions. However, there is scattered or contradicting information about the distribution and fate of heavy metals through the various thermal treatment processes due to limiting intake in the literature regarding the comprehensive analysis of heavy metals. It was realized that the accumulation of heavy metals in sewage sludge depends on the treatment process of wastewater used in treatment plants (Udayanga, Veksha et al. 2018). ICP spectrometer was used to determine heavy metals' concentration for biosolids by mg/kg^2on a wet basis, and results of statistical analyses are illustrated in tables 8 and 9. There was a highly significant difference of available zinc at 0.000 P-value and no significant differences for Aluminum with a P-value of (0.008). Additionally, the same was recorded for the Potassium (K) with a P-value of (0.038) without any differences among treatments. Statistical analysis of the Magnesium (Mg) indicated significant differences versus control treatments at 0.059 P-value as confirmed by Tukey pairwise comparison. By extension, Sodium (Na) presence reflected substantial differences with a P-value of (0.011). The results were not similar for Arsenic (As), Chromium (Cr), Nickle (Ni) and Lead (Pb) with P – the value of (0.104), (0.873), (0.671) and (0.252) in rows. A slight variation appeared with Tin (Sn), which showed a significant difference of (0.048) P-value. For all the above results of heavy metals, the assessed levels of both nutrients and pollutants can be considered very promising after comparison against the regional and international standards or acceptable ceiling of heavy metals. The outcomes can therefore indicate a clear conclusion about the quality of biosolid produced in Qatar.

Table 8: Analysis of Variance for Heavy Metals in Bio-solid

SOV	DF	MS (mg/kg)														
		Wt. taken gm	AL	K	Mg	Na	As	Cd	Co	Cr	Ni	Pb	Sn	Zn	Cu	Hg
Treatment	2	**0.0003**	**5.4***	**0.87***	**17.78**	**1.21***	**0.00001**	**N.D**	**N.D**	**0.000004**	**0.000007**	**0.00007**	**0.000026***	**0.005**	**7888.7****	**N.D.**
Error	9	**0.0006**	**0.63**	**0.18**	**4.53**	**0.15**	**0.000004**	**N.D**	**N.D**	**0.00003**	**0.00001**	**0.00004**	**0.000006**	**0.011**	**205.5**	**N.D.**
Total	11															

ND = Non detected Minimum Detectable level of Cd = 0.2

*= Significant differences Minimum Detectable level of Co = 0.3

**= Highly significant differences Minimum Detectable level of Hg = 0.01

Table 9: Heavy Metals means of Bio-solid samples with standard deviation

Heavy Metals	MS			
	Mean1/ samples of Bio-solids taken in February 2018	Mean2/samples of Bio-solids taken in May 2018	Mean3/samples of Bio-solids taken in August 2018	Standard Deviation of Means ±
Wt taken,gm	0.28^{A}	0.28^{A}	0.3^{A}	± 0.009
AL(mg/kg)	5.1^{B}	6.77^{A}	4.54^{B}	±1.1
K(mg/kg)	3.3^{A}	3.45^{A}	2.61^{A}	± 0.4
Mg(mg/kg)	11.1^{A}	14.6^{A}	10.76^{A}	± 2.1
Na(mg/kg)	3.6^{A}	2.5^{B}	3.015^{AB}	± 0.5
AS(mg/kg)	0.002^{A}	0.005^{A}	0.004^{A}	± 0.001
Cd(mg/kg)	ND	ND	ND	/
Hg(mg/kg)	ND	ND	ND	/
Co(mg/kg)	ND	ND	ND	/
Cr(mg/kg)	0.04^{A}	0.04^{A}	0.04^{A}	± 0.001
Ni(mg/kg)	0.02^{A}	0.03^{A}	0.02^{A}	± 0.001
Pb(mg/kg)	0.017^{A}	0.02^{A}	0.02^{A}	± 0.004
Sn(mg/kg)	0.005^{AB}	0.008^{A}	0.003^{B}	± 0.002
Cu(mg/kg)	114.3	30.57	46.87	± 44.4
Zn(mg/kg)	0.92^{A}	0.86^{A}	0.86^{A}	± 0.03

- Means comparison was conducted using Tukey test, each two means with similar letter have no significant differences.
- N.D. = not detected.

- Minimum detectable level of Cadmium 0.2, Cobalt 0.3, Mercury 0.01

1.1.4. Comparison of Pollutants content against International standards

Large quantities of biosolids are generated daily, and substantial volumes are recycled as an organic fertilizer or soil amendment for agricultural crops or landscaping projects. It is of great concern to determine the levels of potential pollutants in the produced sludge to assess its quality after processing for suitable use.Pollutants, notably heavy metals, are a concern because of their potential to contaminate soils and bio-accumulate up the food chain. Numerous countries and international institutions have set restrictions and standards on the quality of the produced sludge and their application rates and prescribed mitigating measures on the potential adverse impacts in the use of bio-solids. The prevailing international standards and ceilings vary and are country-specific (Kulkarni and Goswami 2019). Lack of universal standards which specify the acceptable levels of heavy metals as a global template has led to debates and scientific discussions. Hence, a comparison of this study & experiment outcomes against the primary internationally accepted standards is necessary, where the tested heavy metal types are the specified parameters in the Qatari standards. As stated in Table 9 (Wang, Chang et al. 2019), a comparison shows impressive results of values for bio-solids as currently produced in Qatar. The Qataris government has arranged to supply raw sewage sludge from non-industrial and non-medical sources (Authority 2018). The mean for all sample parameters in the Table above illustrates how Qatar & bio-solids are better than other similar products. The comparative table confirms that concentration levels of heavy metals are below the international minimum acceptable ceiling, and thus, there is compliance. This can be attributed first to the sources of raw sludge, secondly, to the efficient production process and treatment method used, and the stringent policy in managing the sludge accordingly.

Table 10: Comparison of Heavy Metals Content against International Standards

Sludge Quality Standards													
			Agriculture										Landscaping
Parameter	Unit	Weighted Average Sludge Content (2009)	USEPA (Part 503 Rule)	Qatar Biosolid	GCC		Abu Dhabi		Bahrain	Australia and New Zealand		EC(86/278/EEC)	QCS 2014
			Exceptional Quality Limit	Mean of All Samples	Limit	Average as % of Limit Value	Unrestricted Use	Restricted Use	(Proposed)	C1 Soil Contaminant if Ceiling Exceeded Ceiling should not be Used	C2 If Exceeded should not be Used	Upper Limit	Maximum Concentration
Zn	Mg/Kg	801.0	2,800	0.00	500	160%	300	2,500	2,800	200-250	2,500	4,000	200
Cu	Mg/Kg	591.0	1,500	n.d.	400	148%	150	1,000	1,500	100-200	2,500	1,750	100
Ni	Mg/Kg	26.0	420	0.02	200	13%	60	300	420	60	270	400	60
Cd	Mg/Kg	0.9	39	0.2 n.d.	20	4%	1	20	39	11	20	40	1
Pb	Mg/Kg	24.3	300	0.016	300	8%	300	750	300	150-300	420	1,200	150
Hg	Mg/Kg	1.5	17	n.d.	10	14%	1	10	17	1	15	25	1

Cr	Mg/Kg	32.0	/	0.04	300	11%	400	1,000	1,200	100-400	500-3000	/	100
As	Mg/Kg	2.7	18	0.003	10	26%	20	75	41	20	60	/	20
Se	Mg/Kg	1.6	36	n.d.	50	3%	3	50	36	3	50	/	5
Mo	Mg/Kg	9.2	41	n.d.	20	46%	20	75	/	/	/	/	/
Co	Mg/Kg	9.2		0.3 n.d.									
Parameter	Unit	Weighted Average Sludge Content (2009)	USEPA (Part 503 Rule)	Qatar Biosolid	GCC		Abu Dhabi		Bahrain	Australia and New Zealand		EC(86/278/EEC)	QCS 2014
			Exceptional Quality Limit	Mean of All Samples	Limit	Average as % of Limit Value	Unrestricted Use	Restricted Use	(Proposed)	C1 Soil Contaminant if Ceiling Exceeded Ceiling should not be Used	C2 If Exceeded should not be Used	Upper Limit	Maximum Concentration
Mg	%	1.7		36.54									
PH		6.1		6.38									
EC	dS/m	3.5		3.43	10	35%							

OM	%	66.3	63.14	>35
N	%	5.5	53.94	
N03-N	Mg/Kg	<0.1	6.13	
P	%	1.8	19.12	
K	%	0.4	3.14	

- (RECYCLING), (EPA 1997), (Management 1994), (Public Work Authority 2017), (electricity 2016), (Municipality 2011), (van der Krol and Immink 2016).

1.50 Conclusions from Experiment 1:

The experiment has fully assessed the quality of the produced biosolid in Qatar through an in-depth analysis and checking of the most important chemical and physical characteristics of Class A biosolid. The first experiment has analyzed and described the temporal characteristics (chemical and physical) of Qatar’s bio-solids of Class A. Sampling was based on specific time intervals of three months between each sample. However, the results were very promising in terms of stability, but there are still variations recorded regarding the samples. The physical analyses highlighted that the form of pellets complied with the specified pellets size, with some deficiencies in the odor treatment unit, which can be considered as a minor defect. Furthermore, the chemical analysis of parameters like pH, electrical conductivity, organic matter content, among others were was either complied with the local, regional, and international standards or even exceeded these. At the same time, investigating the level of nutrients like forms of Nitrogen and Phosphorus illustrated the richness of the product to be suitable for use as an organic fertilizer or soil amendment.

In addition, the levels of heavy metals as the main pollutant indicated a significant value well below international levels. Spectrometry revealed no detection of several major metals (e.g. Mercury, Cobalt and Cadmium). Relatively, the remaining values of the other heavy metals were even lower than the American EPA standards of exceptional quality sludge (Alvarez-Campos 2019). Based on this experiment's results, the proposed hypothesis concerning the product can be approved because the product is benign for use as an organic fertilizer or soil amender in landscaping projects (Authority 2018). This can be attributed to the processing technology using the Swiss combi treatment method, which the Doha North Sewage Treatment Plant [DNSTP] was designed to adopt as an efficient technology in managing the bio-solid's physical properties, dryness, the particle size of pellets and the levels of pollutants and nutrients (Public Works Authority 2017).

2.0 Experiment 2

2.1 plants characteristics

The experiment attempted to record all the related biological growth observations that can be measured technically. Plant growth analysis is a descriptive, comprehensive and integrated approach that assesses the plant's reaction towards different soil textures and treatments including one with a biosolid mixture (Hunt, Causton et al. 2002), Similarly, it will shed light on the plant's response towards the soil enrichments (Schjoerring, Cakmak et al. 2019). The used parameters were plants height, stem diameter, number of leaves, leaves width, leaves length and number of flowers which are the most essential growth parameters (Eng and Ho 2019). Results, as highlighted in tables 5 & 6, revealed significant differences in overall height for plants at 0.001 P-value, while the best elongation was with soil treatment and (NPK chemical fertilizer plus macronutrient) with a mean of (28.375 cm). These were much expected as a continuous and balanced fertilizing program that can ideally manage any growth deficiencies, especially with intensive fertilizing programs prepared for commercial production (James and van Iersel, 2001). The second treatment was the control treatment with dune sand only (23.125 cm), which can be attributed to petunia's preferences to do well in a drain type of soil and grow better inside the greenhouse (Lim, 2014).

Furthermore, treatments with 5 kg bio-solid and treatment of (5 kg manure, plus 20-liter peat moss) indicated slight differences in plant height for the favor of bio-solid treatment with (18 cm) while treatment of manure plus peat moss recorded (17.125 cm) only. This can indicate that Bio-solid effectiveness in developing the plant's height was better than the combination of (manure + peat moss). The importance of these results with the on the Bio-solid role was that the achievements in plant height gained a better development than the manure and peat moss currently used in Qatar, which is an expressive result of the product richness nutrients.

Stem diameter results indicated significant differences at 0.047 p-value. Comparison of means revealed (4.412 cm) for treatment of (5 kg manure+20 liters of peat moss) followed by the treatment with NPK fertilizer, which gained (3.775 cm). Consequently, the control and biosolid treatments in rows showed (3. 662 cm) and (3.125 cm) stem diameter. Results can be expressed clearly as organic manure and peat moss are excellent sources of major nutrients that positively affect the growth rate (Arancon et al., 2008). Similarly, the calculated chemical fertilizer program was designed to manage any significant deficiencies by fulfilling the whole season's growing needs, furthermore, both control treatment and Bio-solid treatments produced different results. Despite the results interpretation did not give the advantage to the Bio-solid in developing the stem diameter, but, we still can rely on its role by considering the other supportive additives that instructed to be used in the practical field like chemical fertilizers as per the approved government procedure (Hall, 2017). The number of leaves can express the plant's response to the surrounding environment and other agricultural processes like fertilization (Stott, 2019). In other words, it represents an assessment of plants' healthiness (Aswathy and Saravanan, 2019). Monitoring and counting of leaves showed significant differences among various treatments with 0.012 p-value with the highest mean record for NPK treatment (69.25), then (Manure and peat moss) treatment (51.25), along with (44.75) for control treatment and (31.75) for Bio-solid treatment. The noticeable positive effect of NPK treatment can be diagnosed due to the continuous supplementary of required nutrients during each stage of growth as recommended by the commercial producers of petunia plants (El-Mokadem and Mona, 2014). Moreover, many studies have approved heat-treated manure and peat moss as the right plantation media, leading to good results (Burnett et al., 2016). The control treatment of pure dune sand meets the petunia's preferences for well-drained soil texture, whereas it can flourish under greenhouse condition (Lim 2014). Lastly, Bio-solid treatment with the recommended dosage of 5kg/m^2 is still competing with other therapies.

The leaves' width and length and the area of leaves are all considered standard growth analysis parameters in many studies (Shi et al., 2019). However, determination of such parameters can lead to additional evidence about growth, but, in some breeding programs like the petunia, farmers tend to minimize the leaves' length and width for the benefits of budding, flowering, and also to simplify the maintenance process (Trupkin et al., 2019). Hence, this study did not neglect to observe these biological indicators. Due to differences in soil textures, treatments revealed non-significant differences at 0.019 p-value. Treatment of control recorded the best leaf length with a mean of (3.65 cm) followed by the treatment of (NPK and macro elements) (3.29 cm), then treatment of (manure and peat moss) (2.99 cm) and Bio-solid treatment with (2.45 cm). On the other hand, the parameter of leaves length revealed similar non-significant results with 0.016 p-value and by ranking control treatment, first with (5.17 cm), while NPK treatment came second with (4.26 cm) then treatments of (manure and peat moss) and treatment with bio-solid in rows with (3.97 cm) and (3.665 cm). Interpreting these observations can be attributed to the differences in soil textures, nevertheless, gaining the best vegetation with control treatment using dune sand is an explanatory result for growth without soil additives as the petunia prefers well-drained soil. In another way, the trace presence of nutrients required for budding and flowering in dune sand will direct the whole growth towards the vegetative parts as the available nutrients in the soil will be exploited for the benefit of improving vegetation. Similarly, a balanced chemical fertilizing program like in NPK treatment will intensify plants' overall conditions, including the green parts. Furthermore, the remaining couple of treatments of manure plus peat moss and treatment of bio-solid also gave promising results with slight differences depending on the availability of nutrients and the enhancement of water holding capacity-which is also an additional parameter to enhance green parts promote the overall condition of plants (Zhao et al., 2019). Subsequently, we should bear in mind that the pure organic fertilizers are slower in releasing nutrients based on soil microbiological agents' activities to make it ready to be utilized by the plants. The short life cycle of the seasonal petunia reached the end before the readiness of these nutrients. Within the same context, flowering is another parameter monitored in this study to determine the response of petunia plants for different plantation media.

Without a doubt, there are lots of interrelated factors that affect blooming and flowering like weather, the amount of light that plants receive, and temperature (Denisow, 2009). Nevertheless, the level of nutrients and the soil texture mainly influence the flowering (James and van Iersel, 2001). Flowering observations highlighted highly significant differences between treatments at 0.000 p-value. The NPK treatment showed the highest blooming with a mean of (15.25) flower then, the treatment of (manure and peat moss) recorded (9.75). In contrast, control and bio-solid treatments are reflected (8.5) and (5.25), respectively. This can be abbreviated by noticing that the treatments with organic additives need time before being available for plants uptake, which is not possible for plants with short life cycle like seasonal petunia. Furthermore, it can never take coupe with balanced and fast release NPK nutrients. In contrast, the element would be available for plants within a short period, especially phosphorus. Further illustration is highlighted by the tables of analysis (Table 11 and 12).

Table 11: Analysis of Variance for Tested Plants Characteristics

		MS					
S.O.V	DF	Plant height cm	Stem diameter cm	Number of leaves	Leaves width cm	Leaves length cm	Number of flowers
Rep	3	17.34	0.24	206.2	0.06	0.3	70.5
Treatment	3	108.26	1.1	974	1.02	1.6	69.3*
Error	9	8.28	0.28	147.6	0.18	0.28	3.9
Total	15						

*=Significant

differences

Table 12: Plants Characteristics Means of *Petunia Atkinsiana* and Standard Deviation

Treatments	plants height mean cm	SD	Stem diameter mean cm	SD	No. of leaves mean	SD	Leaves width mean cm	SD	Leaves length mean cm	SD	No. of flowers mean	SD
5 kg/m² of bio solid	18.00	± 1.3	3.10	± 0.59	31.75	± 8.0	2.40	± 0.2	3.67	± 0.71	5.25	± 4.57 C
Control treatment Sand only	23.13	± 3.0	3.60	± 0.75	44.75	± 9.9	3.65	± 0.3	5.17	± 0.64	8.50	± 2.08 BC
NPK + Macro elements	28.38	± 4.6	3.78	± 0.28	69.25	± 10.5	3.29	± 0.4	4.26	± 0.10	15.25	± 4.92 A
5 Kg/m² of manure + 20 Lit. peat moss	17.13	± 3.0	4.41	± 0.27	51.25	± 19.3	3.00	± 0.49	3.97	± 0.50	9.75	± 5.73 B

- **Means comparison was conducted using Tukey test, each two means with similar letter have no significant differences.**

2.2 Conclusion

By reviewing the observational results for growth analysis and the statistical analysis, it can be generally concluded that the recommended dosage of bio-solid as per the Qatar construction specifications of 5 kg/sq works fine as a soil amendment. There are significant variations with other soil textures like NPK plus macro elements and manure plus peat moss. Nevertheless, it’s still possible to gain better growth development with different application rates, which this study will investigate in the third experiment. Furthermore, the current experiments have been arranged under the greenhouse conditions, and variations are expected even if they are managed in the field due to many other interacted factors like the slow release of nutrients for the pelletized form of class A biosolid which was intentionally managed by producers to cover nutritional issues along the whole season. Therefore, it has become a distinctive need to analyze the soil to be aware of the proposed dosage's chemical effect against other treatments before assessing the recommended application rate as a replacement of manure. It is also recommended to consider the benign quality in terms of the level of pollutants and nutrients.

3.0 Chemical analysis

Results of pH measurements highlighted significant differences among treatments at 0.000 p-value. Comparison of means found that the soil texture with bio-solid indicated the highest neutrality and optimized texture with a mean of (6.925 ms/cm), which lies within the range of the plant's preferences (Bhuyan et al. 2019). The treatment of manure and peat moss had a pH mean of (7.6), which can be attributed to the effect of peat moss as its pH is mostly below (4.0). Then, an analysis of NPK and control treatments with dune sand only recorded a pH value of (8.175) and (8.625) in rows. Records can be expressed due to Qatar and other GCC countries' alkaline soil nature, as stated by (Al-Zubari 1998). The components of such types of sandy and calcareous soils tend to be base-like, where its substance releases hydroxyl ions (OH^-) (Attia 2019). However, plants prefer a neutral pH of 5.5-7.0. Many types of plants are acclimatized to grow in a broader pH range, with differences in their tolerance capability (Bhuyan et al., 2019). Therefore, pH is a significant parameter to be investigated to evaluate the amendment effect to neutralize, increase, or decrease the soil's pH level. Based on these outputs, the study can indicate a positive effect of Bio-solid in neutralizing the pH value in Qatar's alkaline soil to make it tolerable for a wide range of plants. This significant improvement can positively change soil's nature as the organic matter last for a more extended period than the chemical fertilizers; meanwhile, with the expected repeated application, it will achieve the neutral ideal level for plants to grow without being affected by the stress of alkalinity.

The significant differences continue to appear with the electrical conductivity parameter at 0.000 p-value. EC is a central parameter in analyzing the soil texture (Hamdi et al., 2019). In other words, land zone groupings are based on it due to their significant correlation with different physical and chemical characteristics of soil textures (Delbari et al., 2019). Hence, it has become a decisive parameter, which works together with GPS systems to classify the arable lands and their properness for a specific crop (Moral et al., 2019). It worth’s noting that all figures were below the minimum acceptable level, which is a promising indicator. Means highlighted that control treatment scored the lowest EC with (0.075 ms/cm) followed by NPK and macronutrients' treatment with (0.11 ms/cm). The difference between them is the usage of fast-release chemical fertilizers with the NPK treatment. These results can be attributed to the well-drained soil texture and salts' daily leaching by irrigation (Javadi et al., 2019). Similarly, the treatment with (manure and peat moss) recorded a mean of (0.135 ms/cm), which would be expected due to the higher water holding capacity created by these soil additives that increase the level of salinity (Bohlouli et al., 2019). Lastly, the mean of bio-solid treatment is indicated as (0.6475 ms/cm). It is the highest record among treatments, which can be explained by the level of salinity in the product in addition to the pelletized character of class A bio-solid-arranged to ensure a slow release of nutrients (Shin et al., 2019). These results are to be considered in conjunction with other correlated factors, but, through the comparison, they are still promising as they have a low salinity level as reported and accepted by Qatar construction specifications QCS (Authority Q. S. A.-P. W., 2018).

Statistical results of sodium adsorption ratio (SAR) also reflected significant differences at 0.005 p-value. These descriptive results can be highlighted by checking the mean values, whereas the biosolid treatment recorded the highest sodium adsorption ratio with (0.96), which is still below thirteen and is considered normal concerning the American standards. Following was the control and (Manure plus peat moss) treatments with means of (0.89) and (0.79), while only (0.63) was recorded for NPK treatment, respectively. This significant parameter is used for soil analysis and is mainly for irrigation, particularly in the management of sodium-affected soils (Alwan et al., 2019). Additionally, it is an expression of exchangeable Sodium ions' active status to measure its ability to be absorbed by plants in the soil (Suet al., 2019). Base on the results, the major component of soil textures for all treatments is the dune sand, especially for the control treatment (pure dune sand with 0.79 SAR ratio), which is also the primary component in Bio-solid treatment. Therefore, it can be concluded that most of the SAR levels are attributable to the chemical condition of dune sand. These results provide another good signal concerning the SAR level in Class A Bio-solid.

Statistical analysis indicated significant differences among treatments concerning the organic matters (OM) with a 0.000 p-value. For further elaboration, comparing the gained means indicated that the treatment of bio-solid recorded the highest level of organic matter with a mean of (7.83 %) followed by (Manure and peat moss) treatment with a mean of (3.97 %). The treatment of NPK with (1.27 %) and ended up with the control treatment of dune sand only with a standard of (0.75 %) organic matter. These self-explanatory results can be attributed to a high level of organic matter in the produced bio-solid of Class A, which can be considered as an advantage for the biosolid as there are no questions about the multi-benefits and effects of organic matters in soil physically and chemically. In the same manner, it's an evaluative parameter to justify the soil activities and quality (Rao et al., 2019). Descriptions like enhancing the soil structure, improving the water holding capacity, increasing the biological activities, minimizing and taking up pollutants, and ameliorating fertility are all descriptive terms that are usual when tackling soil organic matter (Khalid et al. 2019).

Concerning the free carbonate percentage % as another critical parameter, statistical analysis for the results revealed significant differences between treatments with a p-value of 0.001. On the other hand, checking the means of each treatment indicates a noticeable variation between Bio-solid treatment with a mean of (1.87) and the control treatment (0.69), additional to that the variation remained to appear with the treatment of NPK with (1.19) level and the treatment of (manure plus peat moss) with (0.87). However, the results concerning this parameter were expected due to the level of free carbonates in Qatar's calcareous soils (Yaalon 1957). Moreover, the levels were not so high to affect the growth as confirmed by petunia plants' presence as indicators. Similarly, recording the highest level for the Bio-solid treatment can be additionally attributed to treatment methodology with lime to reduce wet. However, the level is still low and acceptable (Magaritz et al., 1981).

Total nitrogen tests took place for all treatments, and results of statistical analysis of variance revealed non-significant differences among treatments at a p-value of (0.19).

In the same manner, the average of treatment shows that the bio-solid treatment gained the highest content of total nitrogen with a mean of (2,905) mg/kg, followed by the treatment of (manure and peat moss) with a mean of (1,001) mg/kg, which can be attributed to the high nitrogen content in organic fertilizers as a self-explanatory conclusion with an obvious privilege for the bio-solid as most of the pieces of the literature confirmed its high level of nitrogen (Hall, 2017). The other two treatments, which conformed mainly from dune sand, revealed a mean of (427.00) mg/kg for the control treatment and (413.00) mg/kg for the NPK treatment. The last couple of figures refers mainly to the original low content of nitrogen in dune sand. Whereas the NPK won't create a significant difference due to the daily leaching of minerals with the irrigation water and that fast-release fertilizer is designed to supply a quick dosage from the combination of macro elements to plant without the presence of organic additive that can slow the leaching of minerals. However, the bio-solid is the top treatment in the content of this central element.

For the chloride contents in soil, all treatments came up with a similar record of 0.02 % whereas no differences to be recorded. Above all, chloride, which is the most dominant form in the soil, is also a major nutrient for plants, especially for cell activities in the cytoplasm. In contrast, Cl organizes the main enzyme processes (White and Broadley, 2001). Despite these distinctive needs and roles, the plants require no more than 1 to >1000 kg ha^{-1} dry chloride (Chen et al., 2010). Due to this minimal need, it became irregular to notice Cl deficiencies or absence either naturally or in the agricultural field.

For the Sulphates percentage %, the results indicated significant differences among treatments at 0.01 p-value, Furthermore, the means of various treatments are arranged in descending order, the treatment of bio-solid came first with a mean percentage of (0.092) %, followed by treatment of (NPK and macronutrients) mean percentage of (0.07) %, then the treatment of manure and peat moss percentage of (0.062) and finally the control treatment with a mean of (0.05 %). Interpretation of these results can be considered a logical ranking as the lime is part of the bio-solid thickening process; hence it came first (Hall, 2017). Furthermore, the Ammonium sulfate is a genuine component of most NPK chemical fertilizers formulation processes as a binder of granules, which explains its level in this treatment Zhang et al. (2019). Similarly, Adsorbing sulphate ions by organic manure and peat moss as highlighted by studies can showcase the ratio of sulphate within this treatment (Zhao et al., 2019), and being a part of dune sand treatment is clarified already as a part of the soil in Qatar (Al-Thani and Yasseen, 2017). Pieces of literature specified the threshold presence of sulfate in soils to be 0.2 or 0.3 from the sulfates that can be solubilized by rain or irrigation water (LittleDN, 2009). Meanwhile, a study showed that aerobic treatment of pelletized forming sludge effectively mitigates sulfate's harmful effect in sludge (Xue et al., 2017). Both types of processes are essential in producing the Bio-solid of class-A in Qatar (Public Works Authority 2017).

Results also pointed out significant differences for the Nitrate content among treatments with a p-value of 0.000. The importance of nitrate comes through its significant nutritional role in plant growth (Fredes et al. 2019). Observing the means of treatment shows that treatment of bio-solid recorded the highest concentration of nitrate with a mean of (46 mg/Kg). The results are very much expected as the bio-solid is known for its high contents of all nitrogen forms including nitrate. Similarly, the pelletized form of sludge can ensure a slower release of nutrients which keeps the level high and prevent the nutrients from leaching (Hall, 2017). Subsequently, the control treatment of dune sand only recorded the second high concentration of nitrate with (25 mg/kg), which can be attributed to the low intensity of rainfall in Qatar (Ashfaq et al., 2019); which is referred to as a factor that affects the leaching of nutrients including nitrate. Moreover, the absence of organic compounds in this treatment can be another reason to minimize bacterial functionality towards denitrification of nitrate to gaseous as the soil microorganisms get activated and influenced by the organic matters in soil (Kaviya et al., 2019). For the same reasons and due to the daily irrigation system, the treatment of NPK and macronutrients revealed a slightly less nitrate ratio with (23 mg/kg). Furthermore, the fast-release fertilizers might be leached easier or represented by other forms of nitrogen with higher concentrations (Wang et al., 2019). The lowest concentration was in the treatment of manure plus peat moss. This can be explained by keeping in mind that organic matters are always playing many roles at a time. In contrast, the high organic matter would positively activate the soil bacteria to function intensive denitrification processes (Cao et al., 2019). Along with the leaching of nutrients via irrigation, the soil texture can be highly rich with other forms of nitrogen rather than just the free nitrate (Leskovar and Othman, 2019). The bio-solid treatment chemically maintained that it could be a better nitrate source than other treatments tested within this experiment.

Results of total Phosphorus also revealed highly significant differences between treatments at 0.000 p-value. The bio-solid recorded the highest presence of P as expected, which went far away from other treatments with a mean of (1754.5 mg/kg). Phosphorus is considered the second primary nutrient after Nitrogen (Jiang et al., 2019). In comparison, the second-highest treatment was the treatment of (manure and peat moss) with a mean of (254.71 mg/kg) then followed by NPK and macronutrient treatment and a control treatment with means of (129.60 mg/kg) and (127.12 mg/kg) in rows. The gained records gave an obvious advantage to the organic matter by considering that dune sand is the main component of soil textures for all treatments. The differences were derived from soil additives. Similarly, the bio-solid approved that it's an excellent source of micronutrients like phosphorus, and it's suitable to fertile a barren soil like the dune sand used in Qatar. Furthermore, it shows significant positive differences against other organic matters like manure and peat moss and, at the same time, against chemical fertilizers of NPK and other macronutrients and for sure against the pure dune sand in the control treatment. Many studies that tackled the fertilizing issues in different soils should look at the problems arising from a holistic perspective as many of these parameters are significantly correlated (Lanno et al., 2019). Thus, it needs to be discussed in general, not according to a case-by-case concept.

By considering the above, Both Calcium (Ca) and Magnesium (Mg) indicated significant differences with a p-value of 0.007 for the Calcium and 0.000 for the Magnesium. Additionally, the records indicated that the highest level of calcium was in the control treatment of sand only with a mean of (70,09 mg/kg). In comparison, the second high level was the NPK plus macro elements treatment with a mean of (69,59 mg/kg), followed by the treatment of bio-solid and the treatment of (manure plus peat moss) in rows, with averages of (68,77 mg/kg) and (61,006 mg/kg). Many studies indicated that the level of Calcium in calcareous and sandy soil tends to be higher than in other soil because of the presence of lime (Zouidi et al., 2019). Similarly, other studies suggested not to focus on the debatable Ca: Mg ratio concept rather than examining the level of each element alone and its effect on the plant or yield as a practical means to evaluate the differences in soil and plants reaction towards it accordingly (Schulte and Kelling, 1985). Based on this concept, we can consider the levels of calcium in soil textures of different treatments as not so high as we got a steady growth of the indicative petunia plants. Within the same context, the level of Magnesium illustrated that the highest mean level was for the bio-solid treatment with a mean of (5,69 mg/kg), while the NPK plus macronutrients ranked second with a mean of (4,670 mg/kg) followed by the control treatment of dune sand only with a mean of (4,51 mg/kg), then, the (manure plus peat moss) treatment with a mean of (4,35 mg/kg). Although all realized results are going well beyond the international levels, as in many other places worldwide, these elements are still varying in their level of presence, as many studies indicated (Lyon et al., 1971).

Results also pointed out non-significant differences in Potassium level among treatments at 0.73 P-value. Furthermore, the level of potassium in bio-solid treatment was the highest with a mean of 837.4 mg/kg followed by the treatment of manure and peat moss with a mean of 762.3 mg/kg. This enrichment level can be easily attributed to the organic matter in both treatments as organic matter is known as one of the best sources of nutrients, including potassium (Rahman et al. 2020). Subsequently, the treatments of Control and NPK fertilizer shown levels were (643.2 mg/kg) and (639.1 mg/kg) in rows, which is another explainable result due to high levels of potassium in an alkaline type of soils or calcareous soils due to the presence of lime (Jalali et al., 2020). The acceptable level of growth for Petunia plants in all treatments can be a good indicator that the presence of K is within the normal and sufficient levels of potassium as nutrition.

4. Heavy Metals Bo, K, Zn, Mn, Fe, Al, AS, Cd, Co, Cr, Ni, Pb, Sn.

Results revealed that the Cadmium (Cd) and Mercury (Hg) were not detected, or the level was too low to be detected by considering that the minimum detectable concentration by the spectroscopy is (0.3 mg/kg) for Cd and (0.01 mg/kg) for Hg. At the same time, boron (Bo) was only detected in the bio-solid treatment without having any significant differences between treatments at 0.08 p-value. The detected level was a trace level with a mean of 4.975 mg/kg, the minimum detectable level of boron is <3 mg/kg. Moreover, this trace level is very much lower than the acceptable international ceiling of boron as the comparison with the international standard will highlight it. Furthermore, Zinc (Zn) results revealed significant differences between treatments with a p-value of 0.000. At the same point, means of treatments indicates that bio-solid came up with the highest concentration of (81.9 mg/kg) followed by other treatments in lower levels of 25.9 mg/kg for control treatment, 23.6 mg/kg for (manure and peat moss) treatment and 20.5 mg/kg for NPK treatment. Variations in zinc levels in different soil textures are very much normal, depending on the contents of each of them (Iñigo, Marín et al. 2020). Similarly, the high concentration of bio-solid can be attributed to sludge quality as it's a well-known source of heavy metals, including zinc (Mossa, Bailey et al. 2020). Contrary to zinc, results outputs highlighted non-significant differences concerning the Manganese (Mn) level at 0.4 p-value. Average presence ranked the bio-solid with the higher content of 91.75 mg/kg which is expected to be higher due to the occurrence of heavy metals in sludge based on the sort of input, which comes via sewage discharge as these metals are also sourced from detergents and other residuals of different synthetic chemical products which find its way from houses to the sewerage system and leads to assess the quality of sludge (Public Works Authority 2017). On the other hand, examining the level of iron (Fe) in different treatments and soil textures showed significant differences at 0.004 p-value. Additionally, the level of iron in bio-solid was higher with a mean of 2.7 mg/kg, then the treatment of manure and peat moss came second with a mean level of 1.9 mg/kg, while the NPK treatment and control treatment followed with levels of 1.8 mg/kg and 1.7 mg/kg respectively. The results complied with expectations as the organic materials are always good sources for trace elements or inorganic metals, especially the class A bio-solid (Cuervo, Díaz-Nava et al.). While, the NPK plus macronutrients can also add an extra concentration to the current level in soil (Mulani, Upadhye et al. 2020), and the control treatment is representing the actual concentration in the Qatari soil as it's a poor dune sand texture without any additives (Adenan 2020). For the element of Aluminum Al, statistical analysis reflected non-significant differences between treatments with a p-value of 0.4. At the same time, the highest mean was for the bio-solid 3.7 mg/kg followed in rows by (Manure and peat moss) treatment 3.3 mg/kg, then the NPK and micronutrient treatment 3.3 mg/kg, and finally the control treatment 3.1 mg/kg. On the other hand, similar results were obtained concerning the Arsenic (AS), whereas non- significant differences were recorded at 0.18 p-value. Similarly, the means pointed out that the highest concentration presence for the bio-solid treatment was 2.09 mg/kg followed by (manure and peat moss) treatment with a mean of 1.72 mg/kg while the NPK treatment and the control treatment recorded 1.55 mg/kg and 1.28 mg/kg respectively. The same can be told about cobalt levels as the statistical analysis didn't show any significant differences among different treatments with a p-value of 0.5. However, means of presence are revealed the highest concentration was for (manure and peat treatment) 3.78 mg/kg. The second was for NPK treatment with a mean of 3.61 mg/kg, while the bio-solid treatment recorded only 3.39 mg/kg, and the last treatment was the control treatment with a mean of 2.1 mg/kg. The trace levels of cobalt are another indicator of how heavy metals can be variable in different soil textures. Comparing the three highest treatments with additives against the control treatment, where the cobalt level can be considered toxic normally occurs in Qatar's soils. Thus, it would be easier to figure out how the trace is cobalt, which can be attributed to such additives (Paul, Nkrumah et al.

2020).

In a nutshell, Heavy metals are considered hazardous and dangerous pollutants, especially when they accumulate in soil (Adelekan and Abegunde 2011). These concerns became serious due to their nature. In contrast, these inorganic elements do not respond to microbial or chemical activities to degrade it since it has been introduced to the environment (Bilal and Iqbal 2019). Subsequently, it can severely cause health problems for humans or plants, and other living organisms (Ur-Rehman, Hamayun et al. 2019). However, some of these elements are essential for humans and plants in a trace presence like zinc and copper, but they are likely to be a serious risk in higher concentrations (Gupta, Roy et al. 2019). Due to these reasons and due to the facts indicated by many studies, sludge is one of the major sources of contamination with heavy metals (Turek, Wieczorek et al. 2019). It becomes a distinctive need to check the level of such pollutants in soil fertilized with bio-solid to estimate the potential impacts on humans and plants in the future (Papaioannou, Koukoulakis et al. 2019). Similarly, investigating these pollutants' levels will help in creating a good policy to manage the application rates of sludge without accumulation or without reaching the ceiling limits of these pollutants in soil (Eid, Hussain et al. 2019).

5. Comparison against International acceptable levels of heavy metals

In the following tables, there is a comprehensive comparison between the results of the bio-solid produced in Qatar after mixing it with soil as per the Qatari specs of 5 Kg/Sqm as specified in Qatar construction specifications (Authority 2018) with international and regional limits of bio-solid in soil. It’s essential to bear in mind that the directive parameters vary from one country to another, depending on the soil types. Subsequently, Qatar set its directive parameters tested in our experiments while it’s not necessary to match with other countries' directives. Hence, these tables need to be read following this significant restriction. By checking the considerable differences between the allowable limits and the revealed results, this experiment gives a holistic idea about the effect of the governmental recommended dosage for benign usage. Similarly, it matches the development of the first experiment about Qatar's sludge quality.

Table 13: Comparison with International Soil limits

Heavy metal limit values in sludge

Europe	pH Degree	B	Ca	Mg	K	Zn	Mn	Fe	Al	As	Cd	Co	Cr	Ni	Pb	Sn	Cu	Hg	Se	Mo
Directive 86/278/EEC						2500 - 4000					20-40		-	300-400	750-1200		1000-1750	16-25		
Qatar Biosolid 5 Kg/m2	**pH>7.0**	**4.98**	**68,77**	**5,69**	**837.4**	**81.9**	**91.75**	**2.73**	**3.7**	**2.1**	**N.D.<0.3**	**3.39**	**13.2**	**16.04**	**3.96**	**1.82**		**N.D<0.01**		
Austria	Lower Austria					1500					2	10	50	25	100		300	2		
	Upper Austria					2000					10		500	100	400		500	10		
	Burgenland					2000					10		500	100	500		500	10		
	Voralberg					1800					4		300	100	150		500	4		
	Steiermark					2000				20	10	100	500	100	500		500	10		20
	Carinthia					1800					2.5		100	80	150		300	2.5		
Belgium	Flanders					900				150	6		250	100	300		375	5		
	Walloon					2000					10		500	100	500		600	10		
Bulgaria						3000					30		500	350	800		1600	16		
Cyprus						2500 - 4000					20-40		-	300-400	750-1200		1000-1750	16-25		
Czech republic						2500				30	5		200	100	200		500	4		
Denmark						4000				25	0.8		100	30	120		1000	0.8		
Estonia						2500					20		1000	300	750		1000	16		
Finland						1500					3		300	100	150		600	2		
France						3000					20		1000	200	800		1000	10		
Germany(1)						2500					10		900	200	900		800	8		
Germany(2)	<5% P2O5					1500					2.5		100	80	120		700	1.6		
	>5% P2O5					1800					3		120	100	150		850	2		
Greece						2500 - 4000					20-40		500	300-400	750-1200		1000-1750	16-25		
Hungary						2500				75	10	50	1000/1(3)	200	750		1000	10		20

Europe	pH Degree	B	Ca	Mg	K	Zn	Mn	Fe	Al	As	Cd	Co	Cr	Ni	Pb	Sn	Cu	Hg	Se	Mo
Ireland						2500					20		-	300	750		1000	16		
Italy						2500					20		-	300	750		1000	10		
Kosovo						2500 - 4000					20-40		100 - 500	300-400	750-1200		1000-1750	16-25		
Latvia						2500					10		600	200	500		800	10		
Lithuania	Class 1					300					1.5		140	50	140		75	1		
	Class 2					2500					20		400	300	750		1000	8		
Luxembourg						2500 - 4000					20-40		1000-1750	300-400	750-1200		1000-1750	16-25		
Malta						2000					5		800	200	500		800	5		
Montenegro	Class A					600					5		100	60	120		300	5		
	Class B					1200					10		250	100	200		600	10		
	Class C					2400					20		1000	300	750		1000	16		
Netherlands						300				15	1.25		75	30	100		75	0.75		
Norway						800					2		100	50	80		650	3		
Poland						2500					20		1000	300	750		500	16		
Portugal						2500					20		1000	300	750		1000	16		
Romania						2000				10	10	50	500	100	300		500	5		
Slovakia						2500					10		1000	300	750		1000	10		
Slovenia						100				20	0.5		40	30	40		30	0.2		
Spain						2500					20		1000	300	750		1000	16		
Spain						4000					40		1750	400	1200		1750	25		
Sweden						800					2		100	50	100		600	2.5		
Switzerland						2000					5		500	80	500		600	5		
United Kingdom(4)															1200					

Table1 4: Comparison with other International Soil limits

	pH degree	Heavy Metals in Soil Mg/Kg																		
		B	Ca	Mg	K	Zn	Mn	Fe	Al	As	Cd	Co	Cr	Ni	Pb	Sn	Cu	Hg	Se	Mo
Qatar Biosolid 5 Kg/m2	pH>7.0	4.98	68,77	5,69	837.4	81.9	91.75	2.73	3.7	2.1	N.D. <0.3	3.39	13.2	16.04	3.96	1.82		N.D< 0.01		
USA[(1)]	Calculated values					1460				21	20		1530	230	180		770	8.5	50	9.5
Canada(2)						200-220				12-14	1.4-1.6	20-40	64-120	32-50	60-70		63-100	0.5-6.6	1-1.6	4-5
Australia(3)						200-250				20	1		100-400	60	150-300		100-200	1	3	
New Zealand						300				20	1		600	60	300		100	1		
South Africa						200				2	3		350	150	100		120	1		

[(1)]USEPA 40 CFR Part 503 sewage sludge regulations

Table 15: Comparison with Regional Soil Limits

	pH degree	B	Ca	Mg	K	Zn	Mn	Fe	Al	As	Cd	Co	Cr	Ni	Pb	Sn	Cu	Hg	Se	Mo
Qatar Biosolid 5 Kg/m2	pH>7.0	4.98	68,77	5,69	837.4	81.9	91.75	2.73	3.7	2.1	N.D.<0.3	3.39	13.2	16.04	3.96	1.82		N.D<0.01		
GCC	pH 5-8					300				4	2		150	50	30		100	1	5	3
UAE						150				4	1		100	50	30		100	1	5	3
Abu Dhabi								Soil limit values not set												
Dubai						300					3		400	75	30		150	1	5	3
Oman	pH=>7					300				-	3		400	75	30		150	1	5	3
Saudi Arabia						Controlled by annual addition and cumulative amounts of heavy metals														
Jordan						Soil limit values not set														
Syria						200				20	1		100	60	100		100	1	5	
Palestine						Soil limit values not set														
Tunisia						Soil limit values not set														
Turkey	pH 6-7					150					1		60	50	70		50	0.5		
	pH>7					200					1.5		100	70	110		100	1		

6. Conclusion

The study has to draw a broad conclusion about bio-solid's role with the recommended governmental dosage of 5 kg/sqm. To achieve this, it has tended to discuss the results into different levels to come up with a clear perspective that gathers all these correlated factors of both nutrients and pollutants and highlights the image of the indicative growth of *Petunia Atkinsiana* plants. Based on the results' outputs, bio-solid approved its richness in both macro and micronutrients by recording the highest levels in contents of total nitrogen, phosphorus, and potassium among the treatments. Furthermore, the microelements which are required in trace concentrations like zinc reflected the same presence. The other significant parameters like pH revealed that the bio-solid is the optimum growth media with rich organic matter content with the same context. The same can be told concerning the level of salinity from investigating the electrical conductivity in all treatments. While the comparison between the pollutant heavy metals in soil fertilized with 5 kg/sqm of bio-solid with the acceptable international ceilings of these pollutants in soil approved that the produced bio-solid is very benign to be used as an organic fertilizer without any adverse environmental impacts. Since the study curriculum proposed to follow the holistic perspective in tackling the results in depth by interpreting the outputs of the chemical analysis in conjunction with supportive biological parameters of plants, the research went on to highlight that the growth of Petunia fertilized with bio-solid can be considered as beneficial, especially when realizing that the pelletized form of bio-solid was managed to ensure a slow release of fertilizers comparing to other treatments. The short life cycle of the seasonal Petunia might not give sufficient evidence as this industrial form is requiring a more extended period to be thoroughly homogenized and melted with the soil to function as a good source of nutrients. Nevertheless, the clear acceptable and overall health condition of the tested plants can be an expressive approve of the bio-solid’s positive role as a fertilizer, which also meets the useful outputs of the first experiment concerning the quality of the produced bio-solid in Qatar.

From all the above, there is enough confidence to clearly state that the recommended governmental dosage of 5 kg/sqm of bio-solid can enrich the barren soil in Qatar. Subsequently, no potential adverse impacts were revealed owing to the application of such a level. However, the study is still required to assess different levels with various rates to fully understand the possible consequences of using such a vital soil additive. Moreover, its effects have to be examined on groundwater to specify the criteria concerning the most proper methodology to apply this product without jeopardizing the concept of not reaching Qatar's soil maximum limits. Some of the questions that have not been fully addressed here are to be answered with further elaboration in the next experiments.

Experiment 3

1. Results and Discussion

1.1. Plants' Characteristics

The results of the plants' characteristics are presented in Table 16. Furthermore, a comparison between morphological parameters is highlighted in Figure 2. A close follow-up of vegetative growth and plant development took place earlier to capture sufficient data that critically decrease the plant's response to the nutrients in the soil (Meena, Meena et al. 2021). The results of plants' height measurements show highly significant differences among treatments at a p-value of 0.00. Biosolid treatment of 5 kg/m^2 produced the best height, with an average height of 45 cm, while the lowest height was for the control treatment of soil only with a 20 cm height. Similarly, the treatment with 7 kg/m^2 biosolids developed a height of only 36.6 cm. On the contrary, the gathered data reveal non-significant differences for the stem diameter with a p-value of 0.715. However, thicker stem diameters occurred with biosolid treatment of 5 kg/m^2 with a mean diameter of 6 cm, and the lowest was the control treatment of soil only with a diameter of 4.54 cm.

Furthermore, treatment with 7 kg/m^2 biosolid showed 4.64 cm. The differences in leaf number between the various treatments were significant at a p-value of 0.001, where the highest number of leaves was shown for treatment with 5 kg/m^2 biosolids with 417 leaves. The control treatment recorded the lowest number of leaves 49, and treatment with 7 kg/m^2 biosolids revealed 379 leaves.

Significant differences continue to notably appear for both leaf width and length among various treatments, with a p-value of 0.028 for leaf width and 0.005 for leaf length, respectively. The results of the means gave the treatment with 7 kg/m^2 biosolids the widest leaves with 4.23 cm, while the control treatment of soil only recorded the lowest width of 2.3 cm. Meanwhile, the treatment with 5 kg/m^2 biosolids indicated a mean of 3.74 cm for leaf width. The treatment with 7 kg/m^2 biosolids also showed the highest leaf length with an average of 6.41 cm. Similarly, the control treatment of soil only proceeded to show the lowest leaf length with 3.7 cm, and a mean of 6.08 cm for leaf length was noticed in the treatment with 5 kg/m^2 biosolids. Other significant differences were observed concerning the reproductive structure of *Petunia atkinsiana* at a p-value of 0.002. The results revealed the highest intensity of flowering for the treatment with 5 kg/m^2 biosolids, with a mean of 61 flowers, followed by the treatment with 7 kg/m^2 with a mean of 59 flowers, while the lowest flowering rate was in the control treatment of soil only with an average of 13 flowers. Simultaneously, differences between plants' dry and fresh weight denoted highly significant differences with a 0.001 p-value. The comparison of means can highlight these differences clearly as the control treatment of soil only recorded 11.39 % as the lowest dry weight percentage, while the treatments with 7 kg/m^2 and 5 kg/m^2 biosolids obtained 15.37 % and 14.87 %, respectively.

These results matched those of other studies and the literature, illustrating biosolids' function as rich organic fertilizer with both macro and micronutrients. Being a clear reflection pertaining to the overall development obtained during the whole season, they are also a strong indicator of the efficiency of soil texture as a source of nutrients (Anderson, Walsh et al. 2021). In other words, the results clearly illustrate the efficient functionality of biosolids as an organic fertilizer and highlight their role in developing good biomass over the whole life cycle of petunia plants. However, some parameters showed better indicators in the 5 kg/m^2 treatments than the 7 kg/m^2 treatments, which can be explained by the former meeting the nutritional requirements of petunia better than the latter.

Table 16. Averages and Standard Deviation for Plants' Characteristics according to Different Treatments.

Treatments	Plant Height cm		Stem Diameter cm		No. of Leaves		Leaf Width		Leaf Length		No. of Flowers	
Control	20.00	±0.82	4.54	±0.83	49.33	±3.3	2.33	±0.09	3.77	±0.38	12.67	±0.47
3KG Biosolids	39.33	±3.30	5.27	±1.02	235.00	±48.13	3.77	±0.39	6.00	±0.3	34.67	±13.91
5KG Biosolids	45.33	±3.40	6.06	±2.1	416.67	±69.44	3.74	±0.65	6.08	±0.84	61.00	±3.27
7KG Biosolids	36.67	±3.40	4.64	±0.71	378.33	±94.37	4.23	±0.39	6.41	±0.34	59.00	±2.16

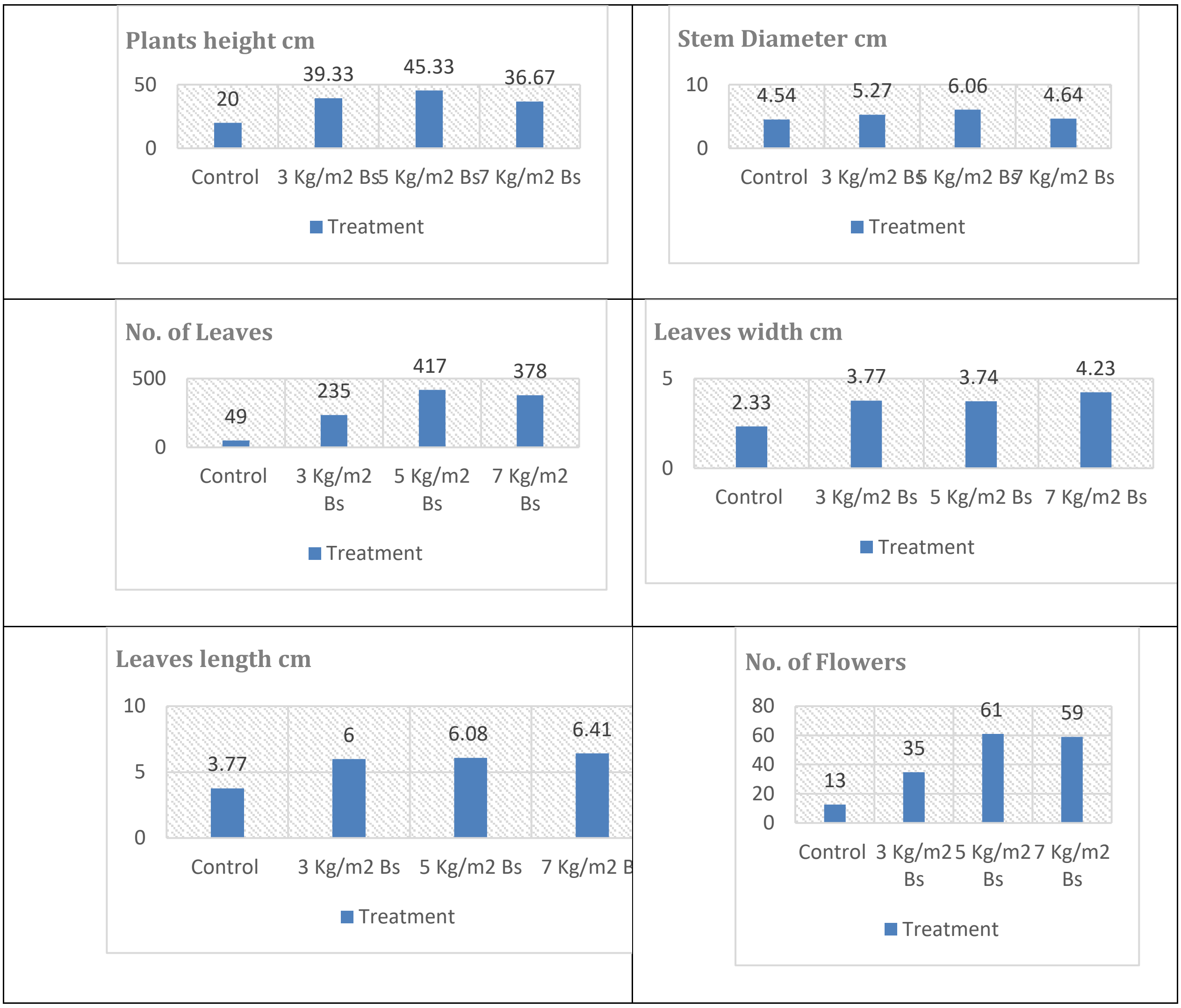


Figure 2. Comparison of Parameters for Indicative Plants' Characteristics.

1.1. Chemical Analysis of Soil

Specifying the ideal and benign rate of biosolid application in Qatar refers to the dose that improves soil properties and promotes plant growth in a significant manner, along with achieving a high level of safety in terms of pollutants. The results of chemical analyses of the soil treated with three different application rates of class A biosolids (3, 5 and 7 kg/m^2), as presented in Table 17, reveal variable levels of significance pertaining to the tests of crucial parameters.

The pH value indicated highly significant differences at a p-value of 0.000. The control treatment of soil evidenced alkaline pH with a mean of 8.27. The biosolid treatments showed success in reducing the pH value to an almost neutral level, where the lowest mean of pH was 6.9 for the treatment with 5kg/m^2 followed by an average pH of 7.0 for the treatment with 7 kg/m^2, which confirms the producers' claim that their biosolid product is almost neutral (6.3–6.5 as measured). Such levels played a role in minimizing the stress on plants as noted by monitoring their indicative characteristics.

Table 17. Averages and Standard Deviation for Chemical Parameters of Different Treatments in Soil.

Treat		pH	Plant Testing/Dry Matter %	Potassium (K) (mg/Kg)	Total Salt as EC(mS/cm)	Sodium Adsorption Ratio	Organic Matter (%)	Free Carbonates (%)	Total Nitrogen (mg/kg)	Chloride Content (%)	Sulphates (%)	Nitrates (mg/Kg)	Total Phosphorus (P) (mg/Kg)	Calcium (Ca) (mg/Kg)	Magnesium (Mg) (mg/Kg)
3 kg/m^2 biosolids	±SD	0.1	0.91	40.58	0.07	0.06	0.62	1.35	0.24	0.00	0.00	6.80	0.17	17.69	0.12
	Mean	7.20	13.62	794.64	0.17	0.52	2.72	1.88	2.17	0.02	0.03	22.67	1.43	75.79	4.99
5 Kg/m^2 biosolids	±SD	0.05	0.83	24.38	0.04	0.03	0.40	0.39	0.00	0.00	0.01	15.08	0.18	2.22	0.20
	Mean	6.97	14.87	844.55	0.28	0.44	3.50	1.04	2.00	0.02	0.04	29.33	1.50	68.69	5.20
7 kg/m^2 biosolids	±SD	0.15	1.71	76.91	0.19	0.11	0.59	0.67	0.82	0.00	0.01	16.97	0.10	7.43	0.52
	Mean	7.00	15.37	788.21	0.36	0.62	3.80	1.04	2.00	0.02	0.04	36.00	1.85	61.26	4.82
Control soil only	±SD	0.09	0.16	56.22	0.004	0.05	0.07	0.27	0.92	0.00	0.01	0.00	0.15	7.10	0.33
	Mean	8.27	11.39	717.60	0.07	0.63	0.76	0.88	2.43	0.02	0.04	24.00	1.28	74.03	4.31

Similar to the pH value, the ratio of organic matter also showed significant differences among the treatments at a p-value of 0.001. Biosolid treatments maintained superiority as compared to the control treatment, with the highest average of 3.80% for the treatments with 7 kg/m^2, followed by the treatments with 5 kg/m^2 with a mean of 3.50 %, while for the control treatment an average of 0.76% was recorded. This logical sequence proves the biosolid richness in organic matter (Ali, Ahmed et al. 2019). Additionally, the test was a revelation for one of the main problems for arable lands nowadays, which is the salinity (Mwando, Angessa et al. 2021). The salinity checkup reflected non-significant differences among treatments with a p-value of 0.095.

Electrical conductivity (EC) revealed non-significant differences at a p-value of 0.095. Furthermore, the control treatment of soil only recorded the lowest salinity with 0.07 mS/cm, followed by the treatment with 5 kg/m^2 biosolids with a mean of 0.28 mS/cm, and the treatment with 7 kg/m^2 biosolids with a mean of 0.36 mS/cm. Considering that the soil-only treatment was taken from the same batch that forms the main components in all treatments, the results can easily be interpreted by attributing this sequence directly to the salts of the biosolids. A major point in this discussion is that the highest recorded salinity for the treatment with 7 kg/m^2 is still below the minimum acceptable level of salinity as specified in Qatar (Authority 2018). Subsequently, the sodium adsorption ratio (SAR) results indicate non-significant differences among the different treatments, with a p-value of 0.071. The obtained results indicate that the presence of biosolids mitigated this ratio as can be observed by checking the average figures of each treatment, where the control treatment of soil only indicated the highest SAR value with a mean of 0.63, while the treatments of biosolids produced, respectively, 0.62 for 7 kg/m^2, 0.52 for 3 kg/m^2 and 0.44 for 5 kg/m^2 biosolid treatment. These non-significant differences and moderated figures obtained for this parameter show that the suggested application rates do not negatively affect this essential ratio and that they help to enhance the soil's properties.

The results of free carbonate analysis indicated non-significant differences among treatments at a p-value of 0.602. Although this result is expected due to the calcareous type of soil in Qatar, further discussion is recommended to shed light on this important parameter. The control treatment of soil only recorded a mean of 0.88%, while the biosolid treatments indicated mean of 1.04% for both treatments of 5 and 7 kg/m^2 biosolids. Similarly, the mean of 3 kg/m^2 biosolids treatment showed the highest level with 1.88%. An important point of these outputs is that the biosolid additives did not significantly increase the percentage of free carbonates in the soil, which might have a bad impact on plants due to alkalinity stress, despite the fact that limestone is commonly used during the thickening and dewatering process of biosolids. Similarly, the results of nitrogen, as a core element in plant growth, present in the soil in different forms (Haynes and Swift 1987), revealed non-significant differences among treatments at a p-value of 0.43. Subsequently, the means of each treatment highlighted that the control treatment of soil recorded a higher total nitrogen value than the biosolid treatments, with 2.43 mg/kg against 2.0 mg/kg for both treatments with 5 kg/m^2 and 7 kg/m^2 biosolids, while the treatment with 3 kg/m^2 biosolids indicated a total nitrogen ratio of 2.17 mg/kg. The interpretation of these results needs to be considered for the assessment of the indicative plant characteristics to be explainable. The plants' vegetative growth, biomass, stems and flowers were much better in biosolid treatments than in the control treatments of soil only as confirmed by either monitoring or by the results of the statistical analysis, which can be firmly attributed to the level of nutrients supplied by the biosolids and the presence of nitrogen. Hence, it can be concluded that a high percentage of nitrogen was initially utilized to develop growth, which is not the same case in the control treatment as the plants adapted to the low level of nitrogen and other nutrients to regulate their growth accordingly. On the other hand, biosolids are well known for their capability of activating soil microorganisms. They work actively on the organic compounds to make them ready and an essential part of these microorganisms, such as the denitrifying bacteria, which represent 10–15 % of soil bacteria, and actively work on soil nitrate to release free nitrogen gas (Liu, Dai et al. 2021). The lack of organic materials required by these bacteria in the control treatment was one reason for the insignificant differences among treatments with a slightly higher level of nitrogen in the control treatment than the biosolids treatment. By contrast, this type of bacteria was actively functioning. Similarly, the tangible differences in growth among the treatments should not be overlooked, as one of the primary reasons behind this is the total content of nitrogen in biosolids. Moreover, the interpretation of nitrate results within this experiment highlighted additional points about these results by indicating non-significant differences for nitrate levels versus control treatments at a p-value of 0.678. Furthermore, the highest mean of nitrate levels was discovered in the treatment with 7 kg/m^2 biosolids with an average amount of 36 mg/kg, followed by treatment with 5 kg/m^2 biosolids with a mean of 29.33 mg/kg, and the control treatment of soil only with an average of 24 mg/kg; the lowest presence was recorded in the treatment with 3 kg/m^2 with a mean value of 22.67 mg/kg. The nitrate receives specific consideration as an inorganic type of nitrogen, which is converted by bacterial action into an organic form in the nitrification process and is capable of utilization by plants for growth and production (Jiang, Zhou et al. 2019). It is interesting that both groups of soil bacterial microorganisms work on the organic material of fertilizers, which in this study are the class A biosolids. However, such observations can be attributed to many points such as the utilization of nitrogen by plants, the addition of the high level of microorganisms' functionality in the texture of biosolids treatment and the variable levels of the nitrification and denitrification processes, which resulted in the currently acceptable level that was successful in developing Petunia plants in season.

The chloride content levels are another important parameter that showed non-significant differences among treatments at a p-value of 0.2. Moreover, the present levels were low in all treatments, which were revealed to be only 0.02%. This is expected as Doha North Sewage Treatment Plant (DNSTP) gathers the sludge from non-industrial and non-medical areas (Public Work Authority 2017). Hence, the effects of the usage of a water softener containing sodium chloride (NaCl) from domestic effluents will not be considered (Morris, Donovan et al. 2009). Similarly, tests for sulphate, which check for the percentage of sulfate salts (Narayani and Sabumon 2019), showed an average presence of 0.04 % in all biosolid treatments as they go through a solid and stable preparation process, while the mean for the control treatment of soil only was 0.03 %. Subsequently, the results revealed non-significant differences between treatments in this parameter at a p-value of 0.757.

Phosphorus (P) is another crucial macronutrient after nitrogen (Jiang, Zhou et al. 2019). Higher levels of phosphorus turn it into a pollutant that needs to be managed (Ashworth 2019). The results reflected non-significant differences versus treatment with a p-value of 0.487. Additionally, the mean figures of P presence show that the highest presence was discovered in 7 kg/m^2 biosolids treatment with 1.85 mg/kg, followed by treatment with 5 kg/m^2 biosolids with an average of 1.50 mg/kg, while the lowest presence of phosphorus was observed in the control treatment with a mean of 1.28 mg/kg. The sequence matches the expectation that the biosolids' phosphorus content is not a discussable issue and was confirmed by many studies (Ali, Ahmed et al. 2019).

Calcium and magnesium are essential secondary nutrients in the soil. The results of the presence of both calcium and magnesium have pointed out non-significant differences among treatments with a p-value of 0.526 and 0.118, respectively. Calcium's highest presence was observed in treatment with 3 kg/m^2 biosolids, with an average of 75.79 mg/kg. Similarly, the control treatment of soil only followed due to the high calcium content in the calcareous type of soil (Gholamnejad, Haghighi et al. 2020), with an average of 74.03 mg/kg. The treatments with 5 kg/m^2 and 7 kg/m^2 biosolids revealed an average of 68.69 mg/kg and 61.26 mg/kg, respectively. Similarly, the highest level of magnesium was observed in the treatment with 5 kg/m^2 biosolids, with a mean of 5.20 mg/kg, while the 7 kg/m^2 treatment recorded a mean of 4.82 mg/kg; the control treatment had an average of 4.31 mg/kg.

Potassium is also a crucial macronutrient required by plants. The results show non-significant differences between treatments at a p-value of 0.203. All the biosolid treatments of different rates recorded a higher potassium presence than the control treatment, whereas the highest level was recorded for treatments with 5 kg/m^2 with 844.55 mg/kg. Subsequently, the treatment with 7 kg/m^2 revealed 788.21 mg/kg, while the control treatment showed 717.6 mg/kg. Although the results show non-significance differences, the impacts of the dewatering and thickening processes during sludge treatment to produce biosolids have promoted the presence of potassium in biosolid treatments. This is because this process incorporates limestone with potassium to obtain fruitful results. On the contrary, the level of potassium in the control treatment can be attributed to the high level of potassium in Qatari soil (El-Batran, El-Damarawy et al. 2020).

1.1. Heavy Metals (Bo, Zn, Mn, Fe, Al, As, Cd, Co, Cr, Ni, Pb, Sn, Hg)

Biosolid applications for agricultural purposes as an organic fertilizer have become a widespread practice. However, based on biosolids' chemical and physical characteristics, this international concept might face some problems, especially regarding heavy metals. The tested elements were based on the specified parameters to be checked by the government authorities in Qatar as they are known as a potential problem in Qatari soil. Similarly, the same parameters were suggested in the regional GCC countries, which have similar conditions (QCS).

The results of the heavy metals test are highlighted in Table 17. This reveals that mercury (Hg) was below the detection limit of the equipment used.

At the same time, the presence of cadmium (Cd) reflected non-significant differences between treatments at a p-value of 0.320. It is worth mentioning that cadmium was below the detectable limit in most replicates, which is <0.3 mg/kg, but it should be pointed out that the detected trace levels were found only in biosolid treatments, while it was undetectable in the control treatment. However, these levels are below the minimum international levels accepted in biosolids as is highlighted by a comparison of Tables 18, 19, and 20. Furthermore, a similar situation appeared with the results of boron (B), which was below the detectable level of <3 mg/kg for all treatments. Only a trace level was discovered in one of the control treatments of soil replicates. This was illustrated statistically, whereas the results indicated non-significant differences between treatments with a recorded p-value of 0.441. This minor detected concentration in one replicate can only be attributed to an error in analyzing it. Subsequently, non-significant differences between the treatments and amounts below the detected level mean that the levels of this element as a potential pollutant can be neglected. The same can be said for aluminum (Al) with non-significant differences and p-values of 0.254. These results were extended to other heavy metal elements, especially since non-significant differences between treatments continue to be observed for cobalt (Co) at a p-value of 0.545, chromium (Cr) with 0.568, nickle (Ni) with 0.07, lead (Pb) with 0.180, arsenic (As) with 0.379 and tin (Sn) with 0.180. The results of these heavy metals were considered promising indications concerning the usage of biosolids as an organic fertilizer (Gholamnejad, Haghighi et al. 2020). Simultaneously, copper (Cu) and iron (Fe) revealed significant differences between treatments as the p-value and statistical analysis were recorded as 0.001 for copper and 0.00 for the iron. Nevertheless, the level of copper was very negligible, as highlighted via comparison against the international levels (Tables 19, 20 and 21).

Other essential elements such as manganese (Mn) and zinc (Zn) were investigated. The statistical results did not reflect significant differences versus the treatment for manganese at a p-value of 0.118. However, the highest was found in the treatment with 7 kg/m^2 biosolids with a mean concentration of 103.53 mg/kg. Simultaneously, the treatment with 5 kg/m^2 showed an average of 91.35 mg/kg, and finally, the control treatment had an average manganese content of 89.61 mg/kg. The level in the control treatment can be firmly attributed to the actual content of manganese in the soil. In contrast, the trace presence in the biosolid treatments, which was slightly higher than in the control treatment, was caused by biosolids' soil additives at different rates. Unlike manganese, the presence of zinc indicated significant differences versus control treatments at a p-value of 0.025 as per the results. Furthermore, by checking the average presence of zinc in each treatment, it was discovered that the control treatment of soil without additives reflected only 36.6 mg/kg, which is low compared to the biosolid treatments, which show 88.42 mg/kg for the 7 kg/m^2 treatment and 80.74 mg/kg for the 5 kg/m^2 treatment. It is clear that the contents of heavy metals in biosolids are higher, including zinc, as pointed out by many studies (Ali, Ahmed et al. 2019). Similarly, the comparison with the international ceilings of heavy metals in soil should highlight the situation and indicate whether there is a problem with these levels or not.

Table 18. Averages and standard deviation for heavy metals according to different treatments in soil.

Treatment		**Zinc (Zn) (mg/Kg)**	**Iron (Fe) (mg/Kg)**	**Aluminum (Al) (mg/Kg)**	**Arsenic (As) (mg/Kg)**	**Cadmium (Cd) (mg/Kg)**	**Cobalt (Co) (mg/Kg)**	**Chromium (Cr) (mg/Kg)**	**Nickel (Ni) (mg/Kg)**	**Lead (Pb) (mg/Kg)**	**Tin (Sn) (mg/Kg)**
3 kg/m^2	±SD	4.68	0.36	0.21	0.39	0.01	1.13	2.40	0.36	0.42	0.31
biosolids	Mean	72.71	3.03	4.16	2.02	0.31	3.01	11.38	14.31	2.63	1.40
5 Kg/m^2	±SD	6.22	0.06	0.35	0.57	0.01	1.29	1.65	1.48	0.36	0.48
biosolids	Mean	80.74	2.61	4.03	2.44	0.31	3.77	12.94	15.47	2.79	1.76
7 kg/m^2	±SD	19.80	1.53	0.48	0.79	0.23	0.86	2.06	0.47	0.89	0.53
biosolids	Mean	88.42	3.65	3.84	1.55	0.50	2.84	14.24	14.12	3.39	2.08
Control	±SD	18.00	0.12	0.27	0.44	N.D	0.53	4.50	1.51	0.41	N.D
soil only	Mean	36.60	1.77	3.45	1.52	N.D.	2.28	10.33	12.06	1.98	N.D

1.1. Comparison against International and Regional Standards:

The comparison with the acceptable international limits will shed a clear light on Qatar's level of treatment, biosolid functionality, and the impact on the soil according to the different experimented rates. These different standards are all measured in mg/kg. This comparison is essential to develop a confident assessment. In contrast, the interpretation of the results of these rates in soil should be integrated with other outputs such as the results of the plants' characteristics. These should be analyzed holistically before recommending the proper application rate, which can significantly promote plant growth and enhance the soil properties without any harmful impact on the soil's chemical and physical characteristics. Moreover, it can be seen that the figures recorded for the different biosolid parameters produced in Qatar are the most benign in the world, which means that pollutants and other toxic heavy metals will not affect the concept of using biosolids as an organic fertilizer. On the other hand, such sustainable practice will increase soil fertility without significant detrimental impacts on Qatari soil. Consequently, the evaluation of these rates will not be considered without investigating these parameters' impacts on the groundwater to finalize it.

Table 19. Comparison between the levels of heavy metals in soil fertilized with three different rates of biosolids and the internationally acceptable standards.

Heavy metal limit values in sludge										
Europe		**Zn**	**Cu**	**Ni**	**Cd**	**Pb**	**Hg**	**Cr**	**As**	**Co**
Directive 86/278/EEC		2500-4000	1000-1750	300-400	20-40	750-1200	16-25	-		
Austria	Lower Austria	1500	300	25	2	100	2	50		10
	Upper Austria	2000	500	100	10	400	10	500		
	Burgenland	2000	500	100	10	500	10	500		
	Voralberg	1800	500	100	4	150	4	300		
	Steiermark	2000	500	100	10	500	10	500	20	100
	Carinthia	1800	300	80	2.5	150	2.5	100		
Belgium	Flanders	900	375	100	6	300	5	250	150	
	Walloon	2000	600	100	10	500	10	500		
Bulgaria		3000	1600	350	30	800	16	500		

Heavy metal limit values in sludge										
Europe		**Zn**	**Cu**	**Ni**	**Cd**	**Pb**	**Hg**	**Cr**	**As**	**Co**
Cyprus		2500-4000	1000-1750	300-400	20-40	750-1200	16-25	-		
Czech Republic		2500	500	100	5	200	4	200	30	
Denmark		4000	1000	30	0.8	120	0.8	100	25	
Estonia		2500	1000	300	20	750	16	1000		
Finland		1500	600	100	3	150	2	300		
France		3000	1000	200	20	800	10	1000		
Germany(1)		2500	800	200	10	900	8	900		
Germany(2)	<5% P_2O_5	1500	700	80	2.5	120	1.6	100		
	>5% P_2O_5	1800	850	100	3	150	2	120		
Greece		2500-4000	1000-1750	300-400	20-40	750-1200	16-25	500		
Hungary		2500	1000	200	10	750	10	1000/1(3)	75	50
Ireland		2500	1000	300	20	750	16	-		
Italy		2500	1000	300	20	750	10	-		
Kosovo		2500-4000	1000-1750	300-400	20-40	750-1200	16-25	100-500		
Latvia		2500	800	200	10	500	10	600		
Lithuania	Class 1	300	75	50	1.5	140	1	140		
	Class 2	2500	1000	300	20	750	8	400		
Luxembourg		2500-4000	1000-1750	300-400	20-40	750-1200	16-25	1000-1750		
Malta		2000	800	200	5	500	5	800		
Montenegro	Class A	600	300	60	5	120	5	100		
	Class B	1200	600	100	10	200	10	250		
	Class C	2400	1000	300	20	750	16	1000		
Netherlands		300	75	30	1.25	100	0.75	75	15	
Norway		800	650	50	2	80	3	100		
Poland		2500	500	300	20	750	16	1000		
Portugal		2500	1000	300	20	750	16	1000		
Romania		2000	500	100	10	300	5	500	10	50
Slovakia		2500	1000	300	10	750	10	1000		
Slovenia		100	30	30	0.5	40	0.2	40	20	
Spain		2500	1000	300	20	750	16	1000		
Spain		4000	1750	400	40	1200	25	1750		
Sweden		800	600	50	2	100	2.5	100		
Switzerland		2000	600	80	5	500	5	500		
United Kingdom (4)						1200				
3 kg/m^2 biosolid average values		72.71	52.60	14.31	0.31	2.63	> 0.01	11.38	2.02	3.01
5 kg/m^2 biosolid average values		80.74	57.40	15.47	0.31	2.79	> 0.01	12.94	2.44	3.77
7 kg/m^2 biosolid average values		88.42	63.70	14.12	0.50	3.39	> 0.01	14.24	1.55	2.84

(1) Regulatory limits as presented in AbfKlärV 1992.

(2) New limits proposed in AbfKlärV 2010.

(3) Chromium VI.

(4) Regulated through limits on application rate and in soil. Values are guidelines for sludge application in grassland.

(5) Public Works Authority, 2017.

Table 20. Comparison between Levels of Heavy Metals in Soil Fertilized with Three Different Rates of Biosolids and the Local and Regional Acceptable Standards.

Middle East		Zn	Cu	Ni	Cd	Pb	Hg	Cr	As	Se	Co
GCC		500	400	200	20	300	10	300	10	50	
UAE		200	100	200	20	200	10	200	20	50	
Abu Dhabi	Unrestricted	300	150	60	1	300	1	400	20	3	
	Controlled	2500	1000	300	20	750	10	1000	75	50	
Dubai		3000	1000	300	20	1000	10	1000		50	
Oman		3000	1000	300	20	1000	10	1000		50	
Saudi Arabia		7500	4300	420	85	840	57	3000	75	100	
Qatar		2500	1000	200	20	300	10	300	10	50	
Bahrain											
Kuwait											
Egypt		2800	1500	420	39	300	17	1200	41	36	
Jordan (1)	Class 1	2800	1500	300	40	300	17	900	41	100	
	Class 2	4000	3000	400	40	840	57	900	75	100	
	Class 3	7500	4300	420	85	840	57	3000	75	100	
Syria (2)	Class A	200	100	60	3	150	1	100	20	5	
	Class B	700	375	125	5	150	4	250	20	8	
	Class C	2500	1500	270	20	300	15	500	20	50	
	Class D	2800	1500	300	32	400	19	600	30	90	
Palestine		As Jordan									
Tunisia		2000	1000	200	20	800	10	500			
Turkey		2500	1000	300	10	750	10	1000			
3 kg/m^2 biosolid average values	Class A	72.71	52.60	14.31	0.31	2.63	> 0.01	11.38	2.02		3.01
5 kg/m^2 biosolid average values	Class A	80.74	57.40	15.47	0.31	2.79	> 0.01	12.94	2.44		3.77
7 kg/m^2 biosolid average values	Class A	88.42	63.70	14.12	0.50	3.39	> 0.01	14.24	1.55		2.84

1. Class 1—agriculture, Class 2—soil improvement, Class 3—landfill.

2. A—gardens, B—public access areas, C—green areas, D—agriculture.

- (Municipality 2011) , (electricity 2016), (145/93 1993), (Authority 2018), (Elbana, Bakr et al. 2017), (Government 2016), (Syria 2007), (EMWater-Project 2005), (Tunisia), (27661 2010).

Table 21. Comparison between levels of heavy metals in soil fertilized with

three different rates of biosolids and other international acceptable standards.

International Standards	Type	Zn	Cu	Ni	Cd	Pb	Cr	Hg	As	Co
EC	(1)	2500-4000	1000-1750	300-400	20-40	750-1200		16-25		
US EPA(2)	Exceptional quality	2800.00	1500.00	420.00	39.00	300.00	1200.00	17.00	41.00	
	Ceiling concentration	7500.00	4300.00	420.00	85.00	840.00	3000.00	57.00	75.00	
Canada (3)	Class A	500-700	100-400	62.00	3.00	150.00	100-210	0.8-2	13.00	34.00
	Class B	1850-4200	760-2200	180-420	10-34	500-1100	1060-2800	4-15	41-170	150.00
Australia (4)	Grade C1	200-250	100-200	60.00	1.00	150-300	100-400	1.00	20.00	
	Grade C2	2500.00	2500.00	270.00	20.00	420.00	500-3000	15.00	60.00	
New Zealand	Grade A	300.00	100.00	60.00	1.00	300.00	600.00	1.00	20.00	
	Grade B	1500.00	1250.00	135.00	10.00	300.00	1500.00	7.50	30.00	
South Africa	Class A	2800.00	1500.00	420.00	40.00	300.00	1200.00	15.00	40.00	
	Class B	7500.00	4300.00	420.00	85.00	840.00	3000.00	55.00	75.00	
Brazil		2800.00	1500.00		39.00	300.00	1000.00	17.00	41.00	
Mexico		2800.00	1500.00	420.00	39.00	300.00	1200.00	17.00	41.00	
China	Soil pH<6.5	2000.00	800.00	100.00	5.00	300.00	600.00	5.00	75.00	
	Soil pH>6.5	3000.00	1500.00	200.00	20.00	1000.00	1000.00	15.00	75.00	
3 kg/m^2 biosolid average values	Class A	72.71	52.60	14.31	0.31	2.63	11.38	> 0.01	2.02	3.01
5 kg/m^2 biosolid average values	Class A	80.74	57.40	15.47	0.31	2.79	12.94	> 0.01	2.44	3.77
7 kg/m^2 biosolid average values	Class A	88.42	63.70	14.12	0.50	3.39	14.24	> 0.01	1.55	2.84

Chemical Analysis of major elements in Soil Leachates

Chemical analysis of leachates was conducted, and the statistical analysis revealed that there were effects of statistically variable differences among various treatments. The results are highlighted in Table 23. Non-significant differences were verified in pH value among treatments at a p-value of 0.231. The observation of means shows that higher pH of 8.33 was recorded in control treatment of soil only, while slightly lower values were noticed in biosolid treatments, for instance, 5 and 7 kg/m^2 had pH values of 8.13 and 8.23, respectively. Although the class A biosolids of in Qatar are almost neutral (Gravand, Rahnavard et al. 2021), this neutrality cannot affect the nature of alkaline soil in Qatar. However, it can be considered to be at the edge of neutrality.

Similarly, electrical conductivity measurements and analysis indicated non-significant differences among treatments at a p-value of 0.6. The sequence of means highlights that higher salinity was found in the control treatment of soil only with 3.12 ms/cm, while the lowest was in the 5 kg/m^2 treatment with 2.72 ms/cm, along with 3.09 ms/cm for the treatment with 7 kg/m^2 biosolids. Such moderated levels did not affect the growth development of the Petunia plants as highlighted by the plants' characteristics. Moreover, it should be recognized that organic matters in biosolids preserve salts and water as they increase the water holding capacity of the soil (EPA 1997), which can create such slight differences in leachates.

Unlike the above parameters, the results reflected significant differences in total nitrogen at a p-value of 0.009. The highest level of total nitrogen was in the treatment with 7 kg/m^2 biosolid with a total of 37.12 mg/L, followed by the treatment with 5 kg/m^2 with a total of 22.21 mg/L, while the control treatment of soil only had the lowest nitrogen content with 6.07 mg/L.

The total nitrogen is expected to show the presence of nitrogen of different forms in the soil, reflected in the leachates, as biosolids are known for high levels of nitrogen (Ali, Ahmed et al. 2019). Furthermore, these results were affirmed by the vigorous growth of Petunia plants in biosolid treatments compared to the control treatment of soil only. Despite these significant differences in total nitrogen, the results of a major form of this mineral (nitrate) revealed non-significant differences at a p-value of 0.119, with the highest presence observed in treatments with 7 and 5 kg/m^2 biosolids with averages of 26.33 and 16.0 mg/L, respectively, while the control treatment showed a level of 4.33 mg/L. Nitrate can be described as a two-sided sword as it is also essential for plants' nutrition. However, its solubility makes it an indicator of groundwater contamination, as shown by many studies and many nutrition manuals. These non-significant differences point out the role of organic material in minimizing the leaching of nutrition and keeping it available for plants within the root zone. Simultaneously, this allows the plants to utilize a good amount of nitrate in the growing process as reflected in the biological parameters of Petunia and the large difference in vegetative growth between the biosolid treatments and the control treatment of soil only. Furthermore, the pelletized industrial form of class A biosolids should not be overlooked as this was designed to simplify the mixing process and to ensure a slow release of nutrients over the whole growing season. Such a prominent feature, which the producers designed for the said purposes, will also unintentionally minimize the harmful impact of nitrate on groundwater and convey a promising message to environmentalists.

The chloride contents indicated significant differences at a p-value of 0.005, with the highest percent for the 7 kg/m^2 biosolids treatment having 0.005 %, followed by the other treatments with 5 and 3 kg/m^2 biosolid having 0.002 %, while the control treatment of soil only possessed a chloride content of 0.001 %. Such significant differences can be attributed to the nature of biosolids rich in different components that contain many nutrients that form several compounds with chloride to increase its presence in soil and soil leachates.

Contrary to the chloride percentage results, the sulfates percentage revealed non-significant differences at a p-value of 0.473. The average presence of sulfates was the highest in the control treatment with a level of 0.3 as compared to the treatments with 5 and 7 kg/m^2 biosolids which had levels of 0.03. The sulfates in soil colloids are known for their variable presence in different forms as organic and inorganic or soluble and insoluble. However, it should be noted that sulfates are not considered a problem in Qatar or any other alkaline types of soil contrary to acidic soils, especially in rainy areas (Jiang, Zhou et al. 2019).

Other significant differences were shown by the results for the second nourishment element for plants, which is phosphorus with a p-value of 0.001. The average presence of phosphorus in the leachates of each treatment illustrated apparent differences between biosolid treatments and the control treatment, as the treatments with 5 and 7 kg/m^2 biosolids reflected values of 2.60 and 2.12 mg/L, respectively, as compared to 0.21 mg/L in the control treatment of soil only. This result is commensurate with the outputs of many studies that looked at municipal biosolid and sewage sludge, which were in agreement concerning the fatty contents of biosolids with phosphorus (Ali, Ahmed et al. 2019). However, it is important to consider that the depth of aquifers in Qatar in calcareous soil and a reasonable rate of biosolids application along with a prohibition on using landfills will avoid contamination problems with phosphorus, especially since it is mandated for all landscaping projects in Qatar to use efficient irrigation systems. Furthermore, the irrigation systems in Qatar supply plants with adequate irrigation to meet their needs and minimize the excessive leaching of nutrients; in addition, the hot climate and high evaporation rate prevent water from going deep towards the groundwater.

The variability was not restricted to the above parameters as the results highlighted non-significant differences for the third important element for plants, which is potassium, at a p-value of 0.11. This result meets the expectations of loamy and alkaline soil in Qatar, where potassium is an abundant element and highly available. The highest potassium level was confirmed in the 7 kg/m^2 biosolids treatment at10.46 mg/L, followed by the 5 kg/m^2 biosolids treatment at 6.10 mg/L, while the control treatment of soil only showed the lowest concentration of potassium in leachates at 4.61 mg/L. The slightly higher level of potassium in the biosolid treatments can be explained due to the industrialization process with lime during the dewatering stage in addition to potassium abundancy in alkaline soil such as that in Qatar. Furthermore, being a soluble element, potassium needs excessive water and acts as a solvent thereby becoming a threat for groundwater; this is not possible with modern irrigation devices, and the current daily applied amount is accuracy in accordance with the actual plants' needs. Subsequently, the calcium and magnesium levels in leachates showed contradictory results, as the statistical analysis pointed out non-significant differences for calcium at a p-value of 0.11 and significant differences for magnesium at a p-value of 0.037. The presence of calcium in leachates, calculated by mg/L, was recorded as the highest in the treatment with 3 kg/m^2 of biosolids at 421.53, followed by the control treatment of soil, at only 380.62 mg/L, and the lowest level was in the treatment with 5 kg/m^2, with a level of 287.57 mg/L. Within the same context, biosolid treatments reflected a higher presence of magnesium, while the lowest level was in the control treatment with 21.51 mg/L. The biosolid treatments show functional ascendancy, starting from 42.43 mg/L for the 3 kg/m^2 treatment and ending with the highest presence of Mg in the 7 kg/m^2 treatment with a level of 66.49 mg/L. It is crucial to reconfirm that the fluctuation in levels did not affect the growth or the balanced texture of biosolids rich with many competing minerals that play a role in this variation. Similarly, the results illustrate that the level of calcium was much higher in general than magnesium and that the calcium abundance was dominant with a variable response to the soil additives. However, magnesium responded positively to the levels of biosolid additives with significant statistical differences.

Unlike the above major elements, sodium is not highly demanded by plants, although it participates in chlorophyll synthesis to a certain extent (Nelson 2003). Furthermore, its high solubility in water might be a problem affecting groundwater quality (Singh and Singh 2020). The statistical analysis of sodium in soil leachates indicates significant differences at a p-value of 0.008. Similarly, the average presence of sodium was recorded at higher levels in the control treatment of soil only with 16.49 mg/L, while the lowest level was found in treatment with 5 kg/m^2 biosolid with 1.18 mg/L, and the 7 kg/m^2 treatment had 1.71 mg/L. The results can be interpreted by highlighting that the lack of obstruction of the leachability of minerals in the control treatment (such as by organic matters) leads to a higher level of leached sodium, unlike the situation with the soils fertilized with a rich organic fertilizer such as biosolids, which act as a barrier against excessive mineral leaching, including sodium (Zharkova, Suhotskaya et al. 2021).

1.1. Chemical analysis of Heavy Metals in soil leachates.

As biosolids are a newly introduced product in the Qatari environment and are rich in nutrients and different types of heavy metals, it is important to investigate and assess the potential impacts of such materials on the environment and also on the groundwater more specifically. This study was designed to satisfy this need via the detailed chemical analysis of soil leachates fertilized with biosolids at different application rates. Furthermore, the study aimed to evaluate the most suitable and non-harmful rate to be recommended for use in Qatar. Based on the discovered leaching behavior, which is discussed below, the analysis of heavy metals can be categorized into three groups: group 1, which revealed positive leachability where the presence of these parameters in the leachates of biosolid treatments was higher than the same parameters in the control treatment leachate; group 2, which indicated a lower presence in the leachates of the biosolid treatments comparing to the same parameters in leachates of the control treatment; and group 3, which showed non-detective concentrations in the leachates or they were below the detection limits.

Group 1

Statistical analysis of soil leachates revealed significant differences versus treatments for boron (B) at a p-value of 0.01. The highest presence of boron was discovered in treatment with 7 kg/m^2 biosolids with an average of 1.01 mg/L, followed by the treatment with 5 kg/m^2 biosolids with 0.98 mg/L, and lastly the control treatment of soil only with 0.62 mg/L. This sequence of results is logical as biosolids are known as a rich source of heavy metals in general, including boron (Ali, Ahmed et al. 2019). However, monitoring the growth of Petunia plants did not reflect any signs or symptoms of boron deficiency during the study period. The results for copper, as per the statistical analysis, reflected high significant differences among treatments showing a p-value of 0.00. Furthermore, the lowest level was for the control treatment with 0.02 mg/L, which is understood as due to the lack of biosolids and its discharged residues. Unlike the control treatment, the treatments with biosolids of different rates indicated an increase starting from 11.02 mg/L for the treatment with 3 kg/m^2, then 13.36 mg/L for the treatment with 5 kg/m^2, reaching the peak with the treatment with 7 kg/m^2 biosolids with an average level of 15.8 mg/L. The differences are clear between treatments as the level of copper positively increased with the application rate, which can be attributed to the copper content of biosolids, as discussed by many studies. However, comparison against the international levels confirmed that these detected levels are trace and can be neglected.

Group 2

Zinc is another heavy metal that interacts with many biological activities of plants and is required in trace levels (Zhang, Su et al. 2020). The results show non-significant differences versus treatments for the zinc presence at a p-value of 0.123. Similarly, the average levels of zinc in the treatments indicated that the biosolid treatments minimized the presence of zinc in soil leachates, which is also pointed out by many studies due to the high amount of organic matter contained in biosolids (Baldi, Cavani et al. 2021). Although zinc is an insoluble metal in water, its reaction with other components can create compounds, which possess solubility and can threaten groundwater when leached by water (Chen, Liao et al. 2021). Considering the above will help in interpreting the results of the discovered zinc presence in soil leachates as the highest level was recorded in the control treatment of soil only with an average of 0.009 mg/L; there is no organic matter to hold it, despite the daily leaching process for zinc compounds with irrigation water. For the biosolids treatments, the results revealed that the 5 kg/m^2 treatment came second after the control treatment with an average level of 0.006 mg/L. simultaneously, both treatments with 3 and 7 kg/m^2 of biosolids recorded a similar average level of 0.003 mg/L. These differences between biosolid treatments can be attributed to the variable release of nutrients from the pelletized biosolids due to the nature of the formula, which was designed to ensure a slow release of nutrients in a process controlled by many variable factors such as the activities of the microorganisms in soil. Similarly, organic matter plays a vital role in minimizing the leachability of nutrients added to other variable factors such as the number and types of zinc compounds formed in soil and their solubility to be leached with water.

Another important mineral and heavy metal is manganese (Mn). The leachability of manganese is linked to many factors including the soil type. While it can be easier to leach manganese in acidic soil, only trace levels are leached in alkaline soils as highlighted by studies. The results reveal non-significant differences among treatments for manganese presence with a p-value of 0.139. Simultaneously, the average presence levels for manganese in the experimental soil leachates indicate a trace presence with the highest distribution in the control treatment, with a level of 0.02 mg/L, while the treatments with 3, 5 and 7 kg/m^2 biosolids, respectively, showed manganese levels of 0.004, 0.008 and 0.007 mg/L. The results can be interpreted by considering that the rich contents of organic matter in biosolids minimize the leaching of heavy metals, including manganese (Gholamnejad, Haghighi et al. 2020). Similarly, the almost-neutral pH of the biosolids produced in Qatar, as revealed by the results, plays a role in lowering the soil pH, which slightly increases the manganese levels in soil as pointed out by (Andrade, Miyazawa et al. 2002). Iron (Fe) is a heavy metal that also interacts with plants and is needed in trace levels (Element 2007). Being a heavy metal with a toxic effect in the case of abundance in soil or groundwater, it is crucial to check its levels in soil leachates gathered from the different treatments in this study. The results reflected non-significant differences among treatments with a p-value of 0.514. Furthermore, the average presence of iron in soil leachates revealed a logical sequence by indicating the highest level of iron in the control treatment with 0.13 mg/L, while the treatments with 3, 5 and 7 kg/m^2 biosolids, respectively, illustrated 0.02, 0.03 and 0.04 mg/L of iron. It was noticeable that the presence of a high amount of organic matter in biosolid treatments acted as a barrier that minimized iron leachability in water, unlike the control treatment with soil only where the leached level of existing iron was slightly higher, as discussed by many studies (Zharkova, Suhotskaya et al. 2021).

The results of the statistical analysis of the leachates indicated non-significant differences versus treatments for aluminum at a p-value of 0.814. On the other hand, the highest level was recorded in the control treatment of soil only at 0.48 mg/L. This level was expected as the presence of aluminum in the alkaline quality of soil in Qatar is not high. Additionally, the lack of organic matter will minimize the cation of heavy metals including aluminum and lead, which are leached with water. Nevertheless, the presence of aluminum in the biosolid treatments was not significantly different as the treatment with 3 and 5 kg/m^2 biosolids revealed aluminum concentration of 0.44 mg/L in soil leachates, while the treatment with 7 kg/m^2 had only 0.43 mg/L.

Arsenic (As) is an extremely toxic type of heavy metal, which is not soluble in water, but can be found in inorganic forms (Nelson 2003). The results of soil leachates revealed significant differences among treatments at a p-value of 0.093. Subsequently, the average presence in all biosolid treatments had a similar level of 0.02 mg/L, while the control treatment showed 0.01 mg/L only. These results agree with many studies in that the biosolids are rich in heavy metals of different types, including arsenic. However, the comparison with international levels sheds a clear light on the level of potential risk from such a level in groundwater.

Within the same context, both cadmium (Cd) and cobalt (Co) had a slight presence. The statistical analysis highlighted non-significant differences for both types of heavy metals with a p-value of 0.532 for cadmium and 0.317 for cobalt. Both heavy metals are insoluble in water, although cadmium salts can be soluble in water, similarly for cobalt (Council 1997). It is essential to highlight that the levels of cadmium and cobalt in soil leachates were very low. However, cadmium indicated almost similar levels for the control treatment and treatments with 3 and 5 kg/m^2 biosolids, with 0.004

mg/L. In contrast, the treatment with 7 kg/m^2 biosolids revealed a cadmium level of 0.003 mg/L. Similarly, the cobalt levels were also trace as the control treatment showed only 0.003 mg/L, while the biosolid treatments showed increased levels: the treatment with 3 kg/m^2 had a cobalt level of 0.002; the treatment with 5 kg/m^2 had 0.004 mg/L; and the treatment with 7 kg/m^2 had the presence of 0.006 mg/L. These non-significant trace levels can be neglected as illustrated by comparing the levels found in the soil with the international levels.

By interpreting these findings, the results show non-significant differences for chromium (Cr) at a p-value of 0.486. In contrast, the same analysis highlighted significant differences for nickel (Ni) with a p-value of 0.026. Although the levels of these two heavy metals are mostly trace, it worth mentioning that being insoluble in water by nature does not prevent them from being a potential contaminant as there are compounds that possess the ability to be solubilized in water such as chromium oxide and chromium hydroxide or nickel chloride (Ayodele, Adekunle et al. 2021). To obtain a clear perspective on their possible role in contaminating Qatar's groundwater, the results highlighted that the chromium levels were very low, with levels of 0.01 mg/L for control treatment and the treatments with 5 and 7 kg/m^2 biosolids, respectively. Only the treatment with 3 kg/m^2 biosolids revealed a chromium presence of 0.002 mg/L. Similarly, the levels of nickle were also trace but with variations, as the lowest presence was in the control treatment with soil only with a level of 0.01 mg/L, while both treatments with 3 and 7 kg/m^2 biosolids recorded levels of 0.02 mg/L, and the treatment with 5 kg/m^2 biosolids recorded a nickle level of 0.03 mg/L. These findings may be affected by many factors such as the pelletized formula or the type of soluble compounds formed by these types of heavy metals. Nevertheless, this does not raise the risk factor as it is below the acceptable international levels as further illustrated by comparison.

The same variations continue to appear with lead (Pb), another important heavy metal pollutant. Lead is a significant pollutant; despite this, it is not soluble in water. The results did not reveal significant differences among treatments for the lead with a p-value of 0.441. Simultaneously, all treatments reflected the same level of 0.007 mg/L, which is the minimum level that can be diagnosed by the spectroscopy. This is below the detectable level, which is the actual situation concerning this primary pollutant.

Group 3

Finally, the chemical analysis of soil leachates indicated non-detectable levels for mercury (Hg) and tin (Sn), which can be considered a positive result for biosolid usage. This further reconfirms the biosolids' quality as both elements cause environmental disturbance in many areas around the world due to their toxicity. Subsequently, this gives additional evidence concerning the manufacturers' claim about gathering all treated biosolids of Doha North Sewerage Plant from non-industrial and non-medical areas. It is worth highlighting that the minimum detectable levels by the spectroscopy for mercury are 0.0001mg/L and 0.01 mg/L for tin.

1.1. Leaching Behavior of Pollutants and Nutrients in Biosolid-Amended Soil with Different Rates

The increase in using biosolids as an organic fertilizer raised several concerns that this study tried to cover in its major parameters in respect to the biosolids produced in Qatar. However, shedding light on the beneficial aspects of using such recycled material should also tackle the risks that might arise from such husbandry practice. One of the main issues might be the leachates from soil fertilized with biosolids. In addition to interpreting the results, it is crucial to highlight the leachability ratio along with how and why to understand the mechanism and action of such nutrients, pollutants and the scientific reasons behind leachability variation, as well as to specify the best practices that help to minimize the hazards of heavy metals and assess their potential impact on groundwater in the future.

Table 22. Comparison of Leaching Rate for Different Biosolid Treatments for Nutrients In Soil Against the Same Parameters in Leachates

Tre.	N2 (mg/kg)	N2 Mg/L	NO3 mg/kg	NO3 mg/L	P mg/kg	P mg/L	B mg/kg	B mg/L	Ca mg/kg	Ca mg/L	Mg mg/kg	Mg mg/L	K mg/kg	K mg/L	Zn mg/kg	Zn mg/L	Mn mg/kg	Mn mg/L	Fe mg/kg	Fe mg/L
T1—3kg Biosolid + Soil	2.17	12.71	22.67	7	1.43	1.87	3	0.24	75.79	40.91	4.99	20.92	794.64	- 0.75	72.71	- 0.006	4.99	- 0.016	3.03	- 0.11
T2—5kg Biosolid + soil	2.00	16.14	29.33	11.67	1.50	2.39	3	0.36	68.69	- 93.05	5.20	34.71	844.55	1.49	80.74	- 0.003	5.20	- 0.012	2.61	- 0.1
T3—7kg Biosolid + Soil	2.00	31.05	36	22	1.85	1.91	3	0.39	61.26	- 31.76	4.82	44.98	788.21	5.85	88.42	-0.006	4.82	- 0.013	3.65	- 0.09
T4—Control Soil only	2.43	6.07	24	4.33	1.28	0.21	4.52	0.62	74.03	380.62	4.31	21.51	717.60	4.61	36.60	0.009	4.31	0.02	1.77	0.13

Table 23. Comparison of Leaching Rate for Biosolids' Heavy Metals in Soil against the Same Parameters in Leachates

Treatments	As mg/kg	As mg/L	Cd mg/kg	Cd mg/L	Co mg/kg	Co mg/L	Cr mg/kg	Cr mg/L	Ni mg/kg	Ni mg/L	Pb mg/kg	Pb mg/L	Na mg/kg	Na mg/L	Cu mg\kg	Cu mg/L	Hg mg/kg	Hg mg/L	Al mg/kg	Al mg/L	Sn mg/kg	Sn mg/L
T1—3kg Biosolid + Soil	2.02	0.01	0.31	0.00	3.01	0.00	11.38	0.01	14.31	0.01	2.63	0.01	0.52	- 4.66	114.03	11.00	0.01	0.00	4.16	-0.04	1.40	0.01
T2—5kg Biosolid + soil	2.44	0.01	0.31	0.00	3.77	0.00	12.94	0.00	15.47	0.02	2.79	0.01	0.44	-15.31	345.50	13.34	0.01	0.00	4.03	-0.04	1.76	0.01
T3—7kg Biosolid + Soil	1.55	0.01	0.50	0.00	2.84	0.00	14.24	0.00	14.12	0.01	3.39	0.01	0.62	-14.78	347.94	15.78	0.01	0.00	3.84	-0.05	2.08	0.01
T4—Control Soil only	1.52	0.01	0.30	0.00	2.28	0.00	10.33	0.01	12.06	0.01	1.98	0.01	0.63	16.49	95.08	0.02	0.01	0.00	3.45	0.48	1.00	0.01

The leachate can be considered as a mirror of all the reactions in the soil (Sims 2000). It gives an idea pertaining to the leachability rate in biosolid treatments compared to the control treatment, which consists of soil only. The difference between the leachates of treatments with biosolids and the control treatment leachates shows the leachability from biosolid material as an additive that needs to be tested, as well as the other variable factors in this study. Simultaneously, the presence level in soil can be another key tool to assess the leachate levels; these main ideas are addressed in comparison Tables (22) and (23), where Table (22) highlights the differences of each pollutant in the leachates between the actual discovered levels in biosolid treatments and the control treatment of soil only. In other words, if the level of each parameter in the biosolid treatments is higher, then the difference shall be highlighted in a positive figure; by contrast, if the control treatment gained a higher level, the figures will be negative (-). Similarly, Table (23) shows the comparison between the discovered level of pollutants in the soil and the level of the same mineral in leachates. In summary, both tables show the link between soil and soil leachates along with the leachability rate of each mineral for a better understanding of the results. The results show strong evidence concerning leachability rates and the overall role of biosolids in the soil for both nutrients and pollutants or heavy metals, as the mobility of such contaminants must be specified in order to create a plan to manage it (Haynes and Swift 1987). The leachability rates are specified in Table (22) and allow us to identify three groups of leaching rates based on comparison against the leachates of the control treatment, which consists of soil only. The first group shows a positive leaching rate, which, as described above, means it has a higher concentration than that of the control treatment as was the case for total nitrogen, nitrate, total phosphorus, boron, magnesium and copper. However, the second group shows a negative leaching rate below that of the control treatment for elements such as potassium, zinc, manganese, iron, aluminum, cobalt and sodium, while the leachates in the third group were below the detection level, such as mercury, tin, lead and cadmium. These variations need to be tackled in depth to understand the nature of the reactions created due to the addition of biosolids. The process specified in this study should be followed by taking a holistic perspective for the obtained results; thus, another comparison in Table 23 was added to compare the discovered rates in soil (mg/kg) and the leachable rates for the same parameters in leachates (mg/L). All the results are to be read in conjunction with each other to reach a conclusion concerning the leachates.

1.1. The Positive Leaching Group

For the total nitrogen in the soil, the control treatment recorded a slightly higher presence (2.43 mg/kg) compared to biosolid treatments. However, all the biosolid treatments showed higher leachability rates than the control treatments. These important parameters indicate that the total nitrogen was subjected to many reactions that create such variability. In particular, by the soil microorganisms nitrifying and denitrifying bacteria where the soil enriched with biosolids can logically be expected to be a good environment for these organic matter-associated bacteria as the rich contents of biosolids stimulate this type of microorganisms to function actively and adequately, affecting the level of nitrogen in the soil (Abd El Magid, Abdelsalam et al.) (El-Batran, El-Damarawy et al. 2020). Furthermore, the plants' high utilization of nitrogen as a nourishing element for growth was reflected in the level of growth achieved in the biosolid-treated petunia plants compared to control treatment based on the utilization of the principal amount of nitrogen to enhance the growth rates, as highlighted in the interpretation of the plants' characteristics (Abd El Magid, Abdelsalam et al.). Above all, the total nitrogen indicated a high positive leachability rate with irrigation water compared to the control treatment. It is essential to highlight that the test was conducted after three months from the starting date of the experiment taking into account the formula of class A pelletized biosolids, which are designed to ensure a slow release of elements (Alvarez-Campos 2019). Therefore, three months were also meant to allow the pellets to be homogenized and melted before gathering the data. Simultaneously, these results mean that nitrogen levels were much higher in the biosolid treatments at the initiation stage of the experiments. However, the optimization processes led by soil microorganisms' activities, plant utilization of nitrogen and positive leaching rates all worked synergistically to minimize the nitrogen levels. The same can be said concerning the other forms of nitrogen such as nitrate, which reflected a positive occurrence in both soil and leachates (rather than only in the control treatment) and can be considered as subsidiary evidence that reinforces this conclusion and shed lights on the type of reactions of such main parameters in both soil and leachates. The results also highlight the positive presence of total phosphorus in both soil and leachates compared to the control treatment, which is expected since biosolids are known to be rich organic fertilizers with several types of nutrients, as discussed by many studies (Public Work Authority 2017). Subsequently, as the second most crucial element for plant growth, the study can rely on the excellent and steady growth that appeared in petunia plants as specified by the tested biological parameters to conclude that a fair amount of phosphorus was utilized by the plants to thrive. Moreover, the trace presence of phosphorus in leachates can be attributed to the pelletized form of biosolids that slows the nutrients' release (Broz 2017); this is in addition to the strong binding nature of phosphorus with soil particles and organic matters, as highlighted by many studies (Public Works Authority 2017) (Jain, Sharma et al. 2021). On the other hand, the heavy metals of boron, magnesium and copper also showed a positive reaction. These important elements are required by plants in trace amounts (Management 1994). The study highlighted several issues. The first and most important is that all the discovered levels of them were well below the international acceptable limits of pollutants, as highlighted in the comparison in Table 21. Similarly, growth monitoring and the analysis of biological parameters did not reveal any signs or symptoms of deficiencies in petunia plants, which means that the steady and stable growth was moving smoothly due to firm and continuous supply of these microelements that were utilized is indicative of the role of biosolids' presence in soil and the leachability rates. The compatibility between the presence of these elements in the soil and the leached rates was obvious; for instance, the level of boron in the control treatment soil was higher than the level recorded in the biosolids treatment soil (4.52 mg/kg compared to 3.0 mg/kg). The same continued to appear in the leachates, and this was also the case for copper and magnesium. Although these levels are below the international limits, it is still crucial to highlight that maintaining good production practices ensures the suitable usage of biosolids for other environmental components such as soil and groundwater.

1.1. The Negative Leaching Group

This group consists of potassium, zinc, manganese, iron, aluminum, cobalt and sodium. The word negative refers to the differences between the concentration of the element in the leachates of the biosolid treatment and the concentration of the leachates in the control treatment for the same elements, which have a minus sign (-). In other words, the presence of biosolids had a negative impact on the levels of these elements in leachates for many reasons that we shall elaborate after discussing these levels. Despite this, not all treatments indicated a negative presence, but it still contains a negative impact. For instance, the 3kg/m^2 biosolids treatment reflected the second-highest level of potassium (K) in soil with 794.64 mg/kg, which is higher than the control treatment of soil only for the same parameter (which revealed 717.60 mg/kg). However, the same treatment showed a negative presence against the control treatment in leachates: 0.75 mg/L compared to 4.16 mg/L for the same parameters in leachates. The results might be more informative when the description is provided that a similar situation took place for other parameters such as zinc, manganese, iron, aluminum, cobalt and sodium. Therefore, questions were raised concerning the reason behind these. Hence, to justify such variances correctly, a study on related tasks associated with the production process and the chemical properties of the material of class A biosolids had to be conducted to find proper answers to shed light on the experiment. It is important to highlight that the sludge passes through several production steps before reaching the field as a pelletized biosolid. The main idea is to digest the sewage product after dissolving in water and make it more stable for use (Al-Thani and Yasseen 2017). This step comprises many stages such as aerobic digestion and thermal treatment at higher levels to ensure a sufficient level of sterilization and to manage the presence of harmful biological agents such as bacteria and fungi (Ayodele, Adekunle et al. 2021) before starting the dewatering or drying process, which includes adding lime to the biosolid to minimize the moisture content (Public Works Authority 2017). Studies have pointed out the importance of the formulation type of biosolids to stabilize and control the hazards from using it as an organic fertilizer (Ali, Ahmed et al. 2019). Simultaneously, the literature indicates that the pelletized formula is the most suitable for several reasons such as minimizing the dust on-site and the simplicity of mixing it with soil particles (Alvarez-Campos 2019). However, this process incorporates a densifying technology to form the product into pellets by molding it with moldy lime as a strong binder that maintains the shape and offers the privilege of turning this stabilized material into a slow-release fertilizer without an adverse impact on the environment (Ayodele, Adekunle et al. 2021). Such methodology leads to the specific description of such material as of EQ, or exceptional quality, which can be used freely without restrictions (Alvarez-Campos 2019). The concept was based on the idea that such formulation type will not be a potential cause of environmental nuisance, or, it will be more suitable for use and without possible detrimental impacts on environmental aspects including the groundwater. Hence, the formula of class A biosolids can be translated into gaining the desired results. Additionally, the high content of organic matters in such recycled products has an imminent advantage by catching and binding many of these pollutants, especially heavy metals (Zharkova, Suhotskaya et al. 2021). This works as a safety layer that minimizes the level of pollutants from being leached into groundwater. The reasons behind their absence can be easily recognized: the pelletized formula and the catching of heavy metals work synergistically to optimize the level of pollutants. Similarly, the literature also revealed that sandy soil's texture acts as another screen that filtrates the heavy metals via firmly binding them with the soil particles (Zhang, Su et al. 2020).

It worth mentioning that the levels of mercury, lead, tin and cadmium were scarcely below the detected levels in the leachates, as indicated from the chemical analysis of soil leachates and interpretation of the results.

1.1. Comprehensive Discussion of Biosolid Soil Leachates

Groundwater is one of the major sources of water for drinking, agricultural and industrial purposes around the world (Jain, Sharma et al. 2021). Geographically, Qatar is a peninsula with a very low yearly average of rain (76 mm). Furthermore, there are various types of soils, which are mainly the lithosol type of limestone rocks and sandy calcareous soil (Baalousha 2016). The remaining types of soil consist of the common Lusabkha soil, which is a salty type and lies mostly in the coastal areas. It is a barren type of soil that is not suitable for agriculture, and few other locations that are commonly known as Rowda are utilized for agricultural purposes (Al-Thani and Yasseen 2017). Rain is the main source for replenishing the groundwater. In addition to being low, rain is also a variable with a higher frequency in the north, decreasing toward the south (Al-Thani and Yasseen 2017). Groundwater has been excessively utilized in Qatar over many decades as it was the only source for agriculture and domestic uses before 1960 (Al-Naimi and Mgbeojedo 2018). Groundwater remains to be used for agricultural purposes only. Such intensive utilization in the past has affected both the quantity and the quality as it became susceptible to contamination from the usage of anthropogenic fertilizers. Biosolids, as a new product in the Qatari environment, deserve to be studied as they are well known for their rich contents of nutrients and pollutants. Thus, this part of the study was designed to determine the level of pollutants in the soil leachates and interpret the results by a comparison set against the international standards. The results indicate that the levels of pollutants in biosolid treatments are well below the international standards in a way that allows the conclusion that there will not be any significant harmful effects on the groundwater in Qatar from the leached water of soils fertilized with biosolids for several reasons:

1. All plantations in Qatar, whether they are for agricultural or landscaping purposes, are mandatorily irrigated by modern irrigation devices such as bubblers or drippers, which ensure a slow and minimal discharge according to the plants' needs within the topsoil or at the root-zone area without any excessive flowrate that can penetrate the soil deeply towards the acquifers or groundwater areas. This is part of Qatar's arrangements to preserve the limited sources of water and to enhance irrigation efficiency (Authority 2018). Most of the groundwater areas which are utilized for agricultural purposes lie in the northern part of the country at a depth of between 60 and 70 meters (Al-Naimi and Mgbeojedo 2018), making it almost impossible to be subjected to any leachates, especially with the low flowrate and sharply calculated daily irrigation figures, which are also minimized with the high evaporation rate in the harsh summer in Qatar.
2. The results highlight good levels of the major nutrients such as N, P and K along with other trace elements, which is essential for enhancing the barren type of soil in Qatar and promoting the vitality of soil microorganisms and the native flora of the desert. These advantages gained from using a recycled material such as municipal biosolids are the core of sustainable practices that far outweigh the disadvantages such as the contents of heavy metals, especially since the discovered levels of pollutants were below the international acceptable levels according to the chemical analysis of both the soil and leachates.
3. Qatar's soil type, rich in sandy loam, and sandy calcareous soils with different layers can be considered a shield against leachates' penetration to the deeper areas. For all the reasons mentioned above and due to Qatar's high-quality biosolids, it can be

stated that the hazards and risk factors from contaminating the groundwater in Qatar by biosolid leachates are minimal (Al Mamoon and Rahman 2017). This conclusion is in accordance with the strict regulations for the suitable and non-harmful application rate. Subsequently, this is also subjected to maintaining the good quality of biosolids and refraining from applying the old concept of landfills to prevent accumulating large quantities of biosolids in a particular area and increasing the risk of leaching the residues of leachates to the aquifers (Emery 1982).

1. Conclusion

An experimental study was performed to evaluate the use of municipal biosolids in soils for ornamental plant cultivation. The first step was conducted to evaluate the biosolids produced in Qatar and their usage as an organic fertilizer to fertilize ornamental plants. The major aim of the first study was to specify the ideal application rate of biosolids with *Petunia atkinsiana* as the experimental plants. Three different application rates of class A biosolids were tested (3 kg/m^2, 5 kg/m^2 and 7 kg/m^2) along with a control treatment of soil only. The treatment took three months, and the morphological parameters that were investigated included plant height, stem diameter, number of leaves, width and length of the leaves and the number of flowers. In sumarry, based on the outputs of the results and monitoring process for all these parameters during three months of the seasonal plant's life cycle, the study highlighted that the biosolids proved to be one of the best organic fertilizers for ornamental plants, while the application rates of 5 kg/m^2 and 7 kg/m^2 being successful to develop plants' vegetative growth and flowering. With the rate of 5 kg/m^2 showing optimal results. The control experiment was last in almost everything, followed by the treatment with 3kg/m^2, which was second in stem diameter and leaf length, as shown in Table 16. The second step focused on conducting a chemical analysis of the soil using the three different application rates of 3, 5 and 7 kg/m^2 and the control experiment of soil only. In conjunction with the analysis of plant characteristics, the chemical analysis revealed promising results regarding the level of nutrients such as nitrogen, phosphorus, potassium and heavy metals. Furthermore, other parameters that were investigated included the PH value, organic matter, total salt, sodium adsorption ratio (SAR), free carbonates, chloride content, sulfates, nitrates, calcium, magnesium, potassium and phosphorus. By contrast, the highest discovered level was well below the regional and international allowable limits, as highlighted in the discussion and comparison tables, which allows us to confidently suggest the levels of 5 and 7 kg/m^2 of biosolids as efficient and safe rates of application to enrich the Qatari soils, which are to be considered safe in terms of the different experimented parameters regarding pollutants. However, it is still required to finalize this study as it shows the overall impacts and reactions resulting from using biosolids with the specified rates as an organic fertilizer. The other targets of this experimental design are to investigate the potential impact of all tested application rates on groundwater by analyzing the soil leachates. The results of the chemical analysis have been well explained and can be affirmed in Table 22–23. The third part of this study was also chemical analysis, with a special focus on biosolids' soil leachates. The parameters experimented here include the pH of the irrigation water, total salts, total nitrogen, chloride content, sulfates, nitrogen, nitrate, total phosphorus, potassium, calcium, magnesium, sodium and heavy metals. The results indicate that the levels of pollutants within the leachates are well below the international standards, allowing the conclusion that there will not be any significant harmful effects on the groundwater in Qatar from the leached water of soils fertilized with biosolids. A further part of this study focused on the leaching behavior of pollutants and nutrients in biosolids adjusted to different rates. The results of this study can be confirmed in Table 22 and 23. This study also involved classifying the positive leaching group, which consisted of total nitrogen and nitrate, total phosphorus, boron, magnesium and copper. On the other hand, the negative leaching group included potassium, zinc, manganese, iron, aluminum, cobalt and sodium. Furthermore, there was another group of non-detected pollutants within the soil leachates.

Experiment Four

1.2.Plants Characteristics

The experiment measured the plant's characteristics on different levels, precisely, the stems, the leaves, and the fruits, to get a sufficient idea about the plants' reaction towards the different types of fertilizers and soil textures. The dry matter results indicated no significant differences between the three levels with a P-value of 0.57 for the length of the stem, 0.69 for the leaves' length, and 0.12 for the fruits. However, the results gained by the biosolid treatments showed their ability to achieve substantial growth against the cow manure and peat moss. The treatment of 5 Kg/m^2 of biosolid gained dry matters of 14.06% compared to 13.86% for the control treatment of 5 kg/ m^2 of manure and peat moss. Moreover, 7 Kg/ m^2 of biosolid scored only 11.81%.

The dry matter of leaves (the 5 Kg/ m^2 of bio-solid) ranked the highest with a percentage of 14.42, followed by control treatment of 5Kg/ m^2 of cow manure with 13.94%, while the 7 Kg/biosolid treatment came third with 13.31%. Unlike the stems and leaves measurements, the dry matter percentage of fruits gave the bio-solids the lead with 5.59% for the 5Kg/ m^2 and 4.63% for the 7Kg/ m^2 bio-solid. The control treatment of 5 Kg/ m^2 manure and peat moss came last with 4.54%. Although there were statistically non-significant minor differences in dry matters for the three levels between treatments, they are still possible to indicate that biosolid treatments are rich enough to develop biomass equal to the one obtained from cow manure and peat moss. Simultaneously, the results as highlighted in table (16) showed that the proper nutritional value of tomato plants meets the dosage of 5 Kg/ m^2 with both bio-solids and (manure with peat moss) in a better way compared to the treatment of 7kg/ m^2 as the plants vary in the required fertilization value (Authority 2018).

Plants' height measurement is a major parameter to assess growth rate (Barry, Aldridge et al. 2012). The study measured the height of the tomato plant to evaluate the efficiency of the organic fertilizers examined in this experiment; the plant's yields and height are linked to more different indicators like life span and fruiting stage. Plants' height has an important correlation with the plant's contents and supplementary nutrients, which should be reflected to enhance it as a decisive growth parameter. Revealed results showed no significant differences among treatments at a P-value of 0.8. This result indicates that the biosolid treatments can be an equivalent source of nutrients for the rich texture of cow manure and peat moss, as indicated by many studies (Sturião, Martinez et al. 2020). The quantitative link between fruit density in tomatoes and the level of nutrients is an essential relation, which has been indicated by many studies (Geng, Wang et al.). This relationship was justified in measuring the gained yield and comparing the fruit density among the different treatments in this study. The statistical analyses highlighted no significant differences among all treatments. With a P-value of 0.44, it can be concluded that both biosolid treatments had developed a similar number of fruits as regular manure and peat moss are used for Qatar's standard production.

Measuring stem diameter in tomato plants is also a sensitive parameter to indicate growth. Although there was a high daily control of water figures inside the greenhouse as the irrigation system is centralized, the variations can be attributed to the other correlated parameters like nutrients and the water holding capacity arising from the organic contents of soil textures. Results reflected no significant differences among treatments with a P-value of 0.81. It is clear that both biosolid treatments developed the stem girth in tomatoes significantly and equal to cow manure and peat moss.

The growth of leaves is another indicator to assess the differences in plants' response to surrounding environments, including nutrients (Arriaza, Blumenstiel et al. 2020). Unlike the outdoor plantation of tomato, the greenhouse plantation, within a controlled environment, will minimize interaction between factors and simplify the assessment methodology. In this study, leaves' length and width measurements were followed to highlight the plants' response to variable treatments and different soil texture rates. Statistical analysis of the results indicates no significant differences among all treatments on the leaves length and width with a P-value of 0.3 and 0.13 for width. It is another indicator concerning the efficiency of bio-solids as an organic fertilizer. In contrast, both 5 kg and 7 kg rates showed similar results for the cow manure and peat moss.

The study measured the yielded fruit size perimeter/cm to comprehend the impact of applying different biosolid rates as an organic fertilizer. Such a qualitative parameter is commonly used to assess the growth and the level of nutrients supplied during the season. The quality of fruits, coupled with plant productivity, is crucial in vegetables and fruit production. The statistical analyses revealed no significant differences among all treatments at a P-value of 0.6. It further illustrated the ability of different biosolid rates of 5kg/ m^2 and 7kg/ m^2 to enhance the quality of fruits, similar to the enhancement gained by using the regular sample of 5kg of cow manure plus 20 Ls of peat moss / m^2. The interpretation of all results above will lead the study to a conclusion, where a holistic view will be accomplished by checking the chemical analysis of the same treatments.

Table (24): Averages and Standard Deviation of Plants Characteristics Parameters for Different Treatments

	Average of Plant height (cm)	**St. D ±**	**Average of Fruit densities (pcs)**	**S St. D ±**	**Average of Stem diameter cm**	**St. D ±**	**Average of Leaves Length Cm**	**St. D ±**	**Average of Leaves width Cm**	**St. D ±**	**Average of Fruit size perimeter /cm**	**St. D ±**
Control 5kg cow manure and 20 L peat moss	114	± 6	6	± 2	7.22	± 0.88	12.20	± 0.33	5.66	± 0.73	9.43	± 1.15
7 KG Biosolids + Soil	116	± 20	8	± 2	6.72	± 0.62	11.53	± 0.66	5.16	± 0.24	9.18	± 0.22
5 KG Biosolids + Soil	106	± 21	8	± 1	7.07	± 0.39	12.56	± 0.66	5.70	± 0.51	8.95	± 0.86

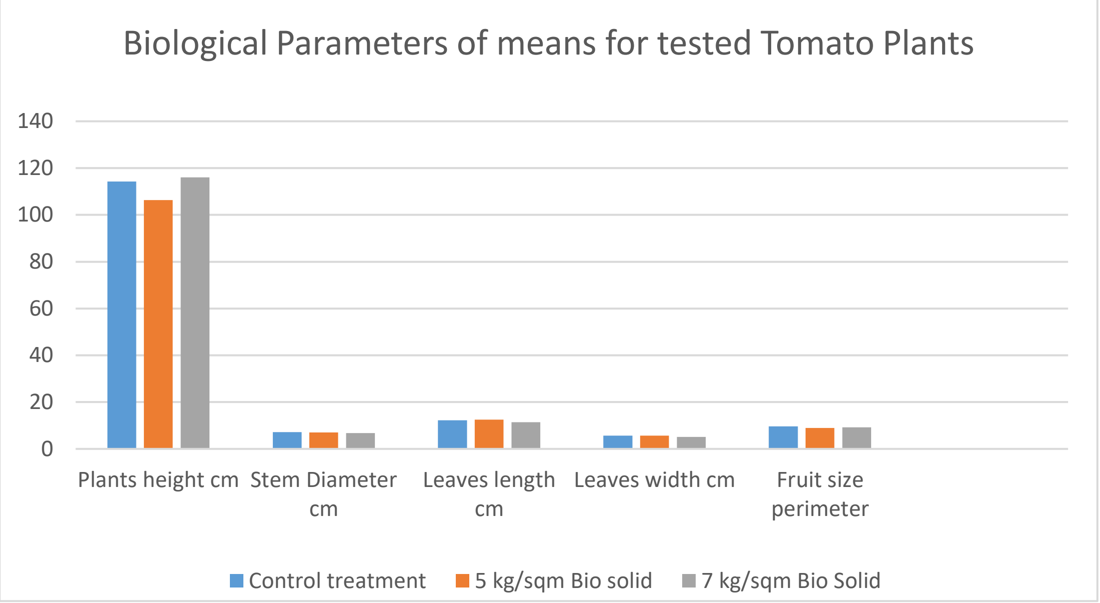


Figure 3: Biological Parameters of Means for Tested Tomato Plants

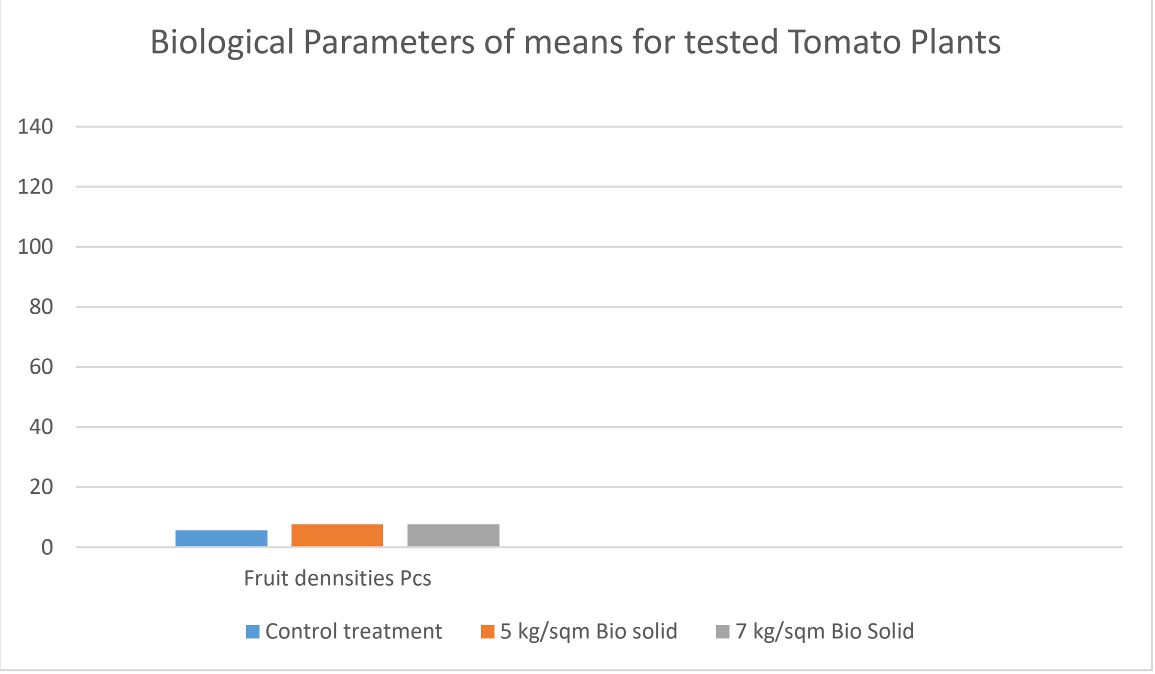


Figure 4: Biological Parameters of Means for Tested Tomato Plants – fruit densities

1.3.Chemical Analysis

Assessing the role of biosolids as an organic fertilizer for tomatoes will be adequately justified by investigating the total Nitrogen's presence level since the tomato plant is incapable of forming its Nitrogen. It requires support from other sources like soil, organic, or agrochemical fertilizers (Zhang, Peng et al. 2019). Statistical interpretation of the results indicated non-significant differences compared to treatments of total Nitrogen levels for the stems, leaves, and fruits with a P-value of 0.28, 0.93, and 0.09 in rows. The mean of all treatments revealed that the highest level of total Nitrogen in stems was for the treatment of 7 Kg/ m^2 of biosolid with a mean of 18.72 mg/kg, followed by the treatment of 5 Kg/ m^2 of biosolid with 8.76 mg/ m^2 then the treatment of 5 Kg/ m^2 manure + 20 Ls/ m^2 peat moss with an average of 8.23 mg/kg. The Nitrogen level with both bio-solids treatments is higher than the manure and peat moss treatment, which can be attributed to the high Nitrogen contents in biosolid (Lowman, McDonald et al. 2013). The treatment of 7Kg/ m^2 biosolid also showed the highest level of Nitrogen in the leaves19.53 mg/Kg, but, this time it was followed by the control treatment of (manure and peat moss) with a mean of 19.11 mg/kg, then the treatment of 5kg biosolid with a mean of 14.84 mg/kg, with slight differences between the other treatments. For the fruits, the leading mean was the treatment of (5kg manure + 20 Ls of peat moss) with a mean of 11.65 mg/kg, followed by the treatment of 7kg biosolid 3.72 mg/kg and the treatment of 5kg biosolid with 3.27 mg/kg of the total Nitrogen. This can be explained due to the formula of biosolids as pellets, which were designed to ensure a slow release of nutrients requiring a more extended period to function precisely in a similar way to the other organic matters.

Boron is one of the leading micro-chemical elements required by plants. Although it is needed in a trace concentration, it plays a pivotal role in the plants' life cycle (Badiaa, Yssaad et al.). Statistical results showed non-significant differences in all treatments with a p-value of 0.56 for stems, 0.35 for leaves, and 0.1 for fruits. Moreover, interpreting the mean figures shed more light on these results as it showed that the highest presence of Boron was at the stems for the 5 kg/ m^2 biosolids with 50.43 mg/kg, followed by the manure and peat moss treatment with 44.57 mg/kg and the lowest concentration was for 7 kg/ m^2 biosolids with 44.18 mg/kg. Similarly, the results of leaves reflected the same ranks with a sequence of treatments with 189.98, 123.89, and 90.72 mg/kg.

In contrast, for the fruits, the 5kg/ m^2 biosolid gained 43.7 mg/kg of Boron, followed by the 7th kg/ m^2 of bio-solids with a presence of 36.42 mg/kg and the lowest was found in the manure and peat moss treatment with a level of 22.12 mg/kg. The differences are statistically non-significant. However, depending on all plants' overall natural growth in these treatments, both biosolid treatments could cope with manure and peat moss' control treatment by being a good source of Boron, which led to natural growth without any signs and symptoms of Boron deficiency.

For the Calcium (Ca), the statistical analysis revealed no significant differences among treatments in all investigated parts at a P-Value of 0.86 for the stems, 0.65 for the leaves, and 0.54 for the fruits. The importance of this microelement and the need to further understand the results led to checking the means of Calcium present in all plant parts. The results showed a higher presence of Calcium in biosolid treatments for all parts. In contrast, the 7 kg/ m^2 of biosolids was in the lead with 82.31 mg/kg in the stems, followed by the 5kg/ m^2 biosolids with 81.39 mg/kg. The last was the manure and peat moss treatment with a mean of 75.84 mg/kg. Only the sequence of treatments showed a variation where 5 kg/ m^2 biosolid showed 230.57 mg/kg, then the 7 kg/ m^2 biosolids with 133.58 mg/kg, and then the manure and peat moss treatment with 123.22 mg/kg. Subsequently, the level of Calcium in fruits reflected the same sequence with a mean of 48.84 mg/kg for the 5 kg/ m^2 biosolid and 23.92 mg/kg for the 7 kg/ m^2 bio-solid, followed by the control treatment of manure and peat moss with a mean of 5.26 mg/kg. These results can be considered as the biosolids well-recognized for their high content of minerals, and there is no concern that the soil had biosolid additives. These important micro-elements perform better than the control treatment if they have good and healthy growth during the whole experiment.

Copper (Cu) is another micro-element that is needed by plants in trace concentration. The role of Copper can be abbreviated by mentioning its function in carbohydrate and chlorophyll synthesis and being a critical factor in Nitrogen's metabolic process (Samarajeewa, Schwertfeger et al. 2020). Results revealed no significant differences among treatments of stems and fruits of plants with a p-value of 0.81, 0.24 in rows. Unlike the stems and fruits, results for leaves indicated significant differences among treatments at a p-value of 0.05. Taking a look at mean figures of Copper in leaves, the highest mean of Cu presence is in the treatment of 5 Kg/ m^2 of biosolid with a mean of 602.04 mg/kg, followed by the treatment of 7 kg/ m^2 of biosolid with a mean of 339.9 mg/kg, and finally the control treatment of manure and peat moss with a mean of 306.6 mg/kg. The results can be explained by the high content of heavy metals in bio-solids comparing to other organic matters and based on the nature of its origin, as indicated by many studies (Guan, Wang et al. 2020). Hence, it is essential to compare the discovered levels of pollutants and nutrients with the internationally acceptable levels of the same minerals in tomato to assess bio-solids actual effect and come up with a definite conclusion.

It is worth noting that utilization of Magnesium by plants can be affected by the high presence of other minerals like Potassium or Calcium, which make it more challenging to diagnose the symptoms of its deficiency and pushes farmers to do whatever they can to ensure its continuous supply via chemical fertilizers (Alejandro, Höller et al. 2020). Results highlighted no significant differences among all treatments about the Magnesium with a P-value of 0.75 for stems, 0.74 for leaves, and 0.28 for fruits. The results comply with the plants' overall conditions where clear evidence of Magnesium deficiency signs and symptoms couldn’t be identified through the continuous monitoring of the plants during the study period. Similarly, the results show that both biosolid treatments were not badly of when compared to regular organic manure and peat moss, a good source of Magnesium. To highlight this conclusion, it is crucial to discuss the Magnesium levels gained in each part for all treatments. For the stems, the 5 kg/ m^2 biosolid treatment recorded the highest rate of Magnesium presence with 21.36 mg/kg, followed by the Manure and peat moss (control treatment) with 19.82 mg/kg and the 7 kg/ m^2 of biosolid with 18.69 mg/kg. The same sequence has been observed in leaves with the presence of 20.23, 12.63, and 12.56 mg/kg, respectively. For the fruits, it was noticeable that both biosolid treatments showed a higher presence of Magnesium with 8.93 mg/kg for the 5 kg/ m^2 treatment and 8.84 mg/kg for the 7 kg/ m^2, respectively. Lastly, the control treatment of manure and peat moss was the lowest with 4.38 mg/kg, which was also highlighted by the fruit's condition and its shape. Generally, the overall yield of the other two treatments seemed better than the control treatment.

Manganese (Mn) is another micronutrient that is needed for tomato production. It is required in trace presence, but due to its central role in cell function and being a key element in chlorophyll synthesis, it is essential to investigate it as it plays a role in forming ascorbic acid, commonly known as Vitamin C (Mondal and Hoque 2020). Results varied for this type of mineral as recorded via statistical analyses, revealing non-significant differences among treatments for the stems and fruits with a p-value of 0.45 for the stems and 0.86 for the fruits. Subsequently, the leaves' statistical analysis showed significant differences among treatments at a p-value of 0.01. Results highlighted that the differences were mainly between manure and peat moss treatment with a mean of 153.86 mg/kg and a mean of 56.85 mg/kg for the treatment of 7 kg/ m^2 bio-solid. On the other hand, the treatment of 5kg/ m^2 had a mean of 103.94 mg/kg. It was expected to find variations in the leaves that are hotspot for chlorophyll synthesis as it is the place of the significant functionality of Manganese. However, all these results did not show any Mn deficiency symptoms on plants, and the differences remained only in leaves. Furthermore, the presence of Manganese in stems and fruits did not reflect any significant differences for these parameters and still showed that the biosolid was fulfilling plants' needs in an acceptable range.

There is no question that phosphorus (P) plays a crucial role in growth, being a significant component in nucleic acid and its multi-roles in increasing fruits' quantity & quality and being a key element in transferring energy, all these factors made it an essential component, especially at the earlier stages of seedling growth. Furthermore, it’s the main reason behind the increase in total soluble solids and flowering in tomatoes (hybrida Plants 2014). Statistical analyses of the complete randomized block design method have revealed no significant differences among all treatments with a p-value of 0.59 for the stems, 0.53 for the leaves, and 0.35 for the fruits. These are the expected results as the organic matter, in general, is rich with macro-elements and particularly the bio-solids (Kissel, Sander et al. 1985). It is crucial to look at the recorded levels of Phosphorus gained from the study for an informed conclusion. The biosolid treatments showed higher content of (P) with 12.89 mg/kg for the treatment of 5 kg/ m^2 biosolid and 10.78 mg/kg for 7 kg/ m^2 treatment of biosolid in the stems comparing to 6.38 mg/kg for the control treatment of manure and peat moss. The same sequence was observed in the leaves with 22.91 mg/kg for 5 kg/ m^2 treatment followed by 16.56 mg/kg for the 7 kg/ m^2 treatment of bio-solid, while the control treatment of manure and peat moss scored 11.47 mg/kg. A slight change was recorded for the fruits as the 7 kg/ m^2 treatment reflected 27.15 mg/kg followed by the 5 kg/ m^2 biosolid 23.49 mg/kg and the lowest was the manure and peat moss treatment with 16.56 mg/kg. Interpretation of the results reveals that both biosolid treatments were better than the manure and peat moss in terms of Phosphorus contents. Although statistical analyses showed no significant differences among treatments, it is still pivotal to record these variations and sequences that highlight biosolid’s essential role as an organic fertilizer.

Unlike other elements, the potassium level tends to be high in alkaline soils like the Qatari (Shabani, Tabatabaei et al. 2012). This element is involved in many key functions like preserving water and balancing ions in tomato plants (Almeselmani, Pant et al. 2009). Furthermore, it manages many processes linked to the formation of proteins and enzymes, sugar distribution, and synthesis (Queddeng 2020). The studies highlighted this element's crucial role in producing high-quality fruit by controlling the percentages of sugars and influencing ripening (Nisa and Khan 2020). The results reflected no significant differences among all treatments by indicating a p-value of 0.4 for the stems, 0.73 for the leaves, and 0.23 for fruits. The relative similarity is not a barrier to investigating the actual treatment means to comprehend these results further.

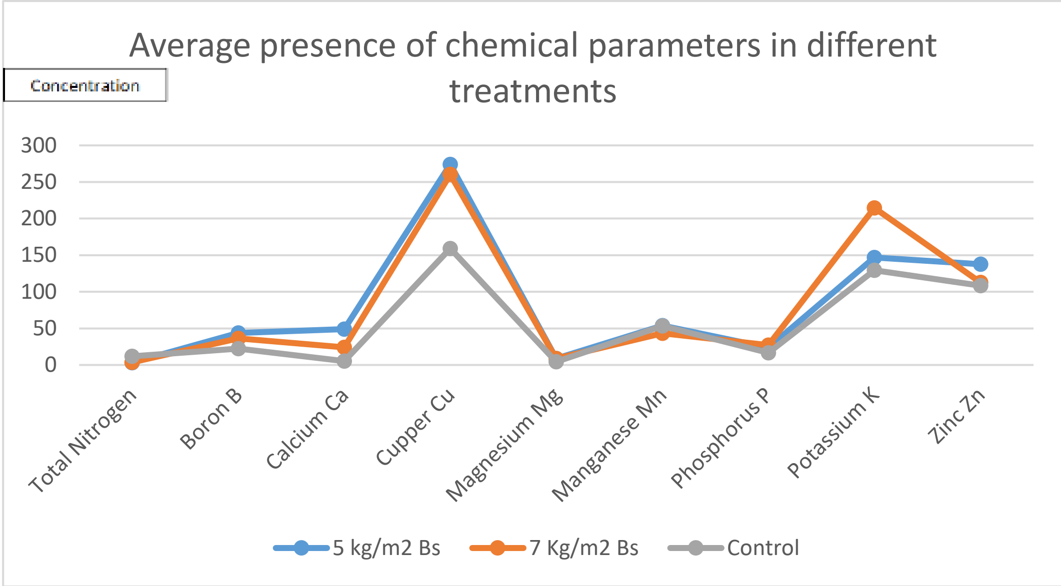
The potassium levels in the stems among the treatments recorded that both biosolid treatments of 5 kg/ m^2 and 7 kg/ m^2 came first with 117.2 mg/kg and 86.7 mg/kg, respectively, while the control treatment of peat moss and manure showed 54.2 mg/kg. For the leaves, the control treatment came second after the biosolid treatment of 5 kg/ m^2 with 120.2 mg/kg, the control treatment 67.4 mg/kg and finally the 7 kg/ m^2 of biosolids with 54.6 mg/kg. The rank was subjected to another sequence for the fruits where the 7 kg/ m^2 showed the highest potassium level with 214.5 mg/kg, then the other biosolid treatment of 5 kg/ m^2 with a presence of 147 mg/kg and lastly, the control treatment with 129.5 mg/kg. These different sequences cannot be considered as variations since the statistical analyses had revealed no significant differences. However, it's tangible evidence about how valuable the biosolid is as a source of a major element for the plants. Such interpretation meets the overall conditions for tomato plants, which were fertilized with biosolids. They superseded the regular organic manure as organic fertilizer, not as a regular soil conditioner, and highlighted no question about its primary role as a fertilizer.

Similarly, as shown in table 25 and line graph 1, (Mn) and (Mg), Zinc (Zn) is involved in enzymatic functions to promote and regulate growth. It takes part in chlorophyll synthesis, and it is needed by plants in trace concentration (Alayu and Leta 2020). Statistical results showed no significant differences among different treatments with a p-value of 0.2 for stems and 0.6 for both leaves and fruits. An investigation of the level of Zinc among treatments in each part revealed that the stem level had the highest presence, which was noticed in control treatment of peat moss and manure with 297.4 mg/kg followed by biosolid treatments with 295.7 for 5 kg/ m^2 and 209.8 mg/kg for 7kg treatment respectively. In the level of leaves, the biosolid treatments were higher than the control treatment with 195.8 mg/kg for the 5 kg/ m^2 and 175.01

mg/kg for the 7 kg/ m^2, while the control treatment showed 127.6 mg/kg. Zinc's superiority is higher in fruits for both biosolid treatments of 5 and 7 kg/ m^2 with Zinc presence of 137.8 mg/kg and 112.7 respectively, as the control treatment revealed only 108.26 mg/kg. The lack of statistically significant differences for all parts and all treatments might help to give clear evidence about the importance of biosolid as a better replacement of manure and peat moss. Nevertheless, it is still crucial to investigate the recorded levels and compare them to the acceptable international levels of each element against the discovered presence in tomato fertilized with biosolid produced in Qatar.

Table 25: Means & Standard Deviations of Chemical Analyses for All Treatment

Treatment	Tot. N	St. D.	B	St. D.	Ca	St. D.	Cu	St. D.	Mg	St. D.	Mn	St. D.	P	St. D.	K	St. D.	Zn	St. D.
Control	11.65	± 5.05	22.12	± 8.32	5.26	± 1.56	159.21	± 92.5	4.38	± 2.26	53.18	± 30.1	16.56	± 6.4	129.54	± 71.4	108.3	± 39.7
5 Kg Biosolid	3.27	± 0.75	43.7	± 10.78	48.84	± 69.30	274.13	± 143.4	8.93	± 4	53.77	± 21	23.49	± 13.9	147	± 90	137.8	± 35.1
7 KG Biosolid	3.72	± 2.38	36.42	± 18.09	23.92	± 23.58	260.27	± 98.8	8.84	± 2.3	43.32	± 21.8	27.15	± 4.2	214.53	± 35.3	112.7	± 47.8



Line Graph 1: Means of chemical analyses for all treatment

1.4. Comprehensive analysis

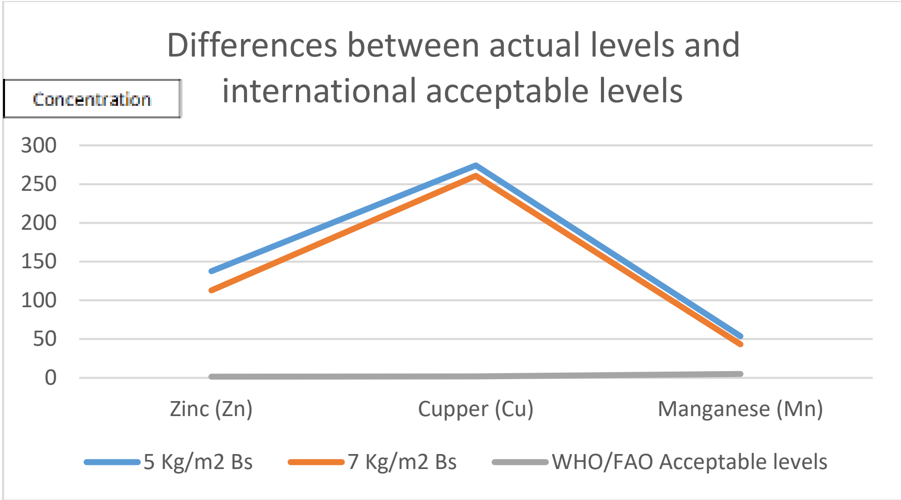
Investigating the nature of these tomato fruits' parameters has revealed many discussion points that go well beyond the regular social resistance against the usage of biosolids to fertilize edible fruits and vegetables. Most of the tested parameters indeed represent major nutrients in fertilizing fruits, including tomato. Nevertheless, it is fundamental to keep in mind that high levels of these nutrients will turn the parameters into toxic substances that accumulate in fruits (Nisa and Khan 2020). As shown in table 16 and line graph 2, both WHO and FAO organizations added restrictions for most of those parameters like heavy metals in tomato fruits, for instance, Zinc, Copper, and Manganese. However, the same organizations didn't specify the maximum presence or acceptable levels for many other nutrients like Nitrogen, Phosphorus, and Potassium (Pivovarov and Pronina 2013). These restrictions might arise from many influencing factors like toxicity, mobility of these nutrients, and affect the quality, which may diminish the importance of these nutrients for plants' productivity, growth, and yields (Nisa and Khan 2020). Looking at the concentrations of macro-elements like N, P, K and, it is evident that they have high levels of nutrients compared with the control treatment. This can be abbreviated by checking its presence in fruits where the nutrients from biosolid treatments were higher than the treatments of the same nutrients in the control experiment without a specific diagnosis of the tomato level of toxicity parameters. However, in some other heavy metals, world's organizations specified the maximum levels that can be presented in tomatoes, mainly, Zinc which is specified to be 1.5 mg/kg. The treatment of 5 kg biosolid recorded 137.82 mg/kg, and the 7 kg Biosolid as 112.71 mg/kg.

Similarly, Copper's maximum acceptable level is 2.00 mg/kg while the 5 kg Biosolid showed 274.13 mg/kg, and the 7 kg biosolid treatment reflected 260.72 mg/kg. Furthermore, the international levels restricted the Manganese's presence to be 5.0 mg/kg. In comparison, the same nutrient revealed 53.77 mg/kg for the 5 Kg biosolid treatment and 43.32 mg/kg for the 7 kg biosolid treatment. These significant differences between the acceptable international levels and the levels discovered in tomato fruits fertilized with biosolids can be sufficient to highlight the unsuitability of biosolids produced in Qatar to fertilize edible fruits. These toxic chemical compounds can accumulate in the human body and be a significant cause of many diseases like cancer (Duan, Xu et al. 2020). The biosolid successfully developed the plants' growth equal to or better than the regular manure. Still, this physiological and productivity enhancement will never be a reason to overlook the toxic presence of heavy metals in fruits. Therefore, these results shall highlight the rightness of specifying it as an organic fertilizer for ornamental plants only. It still needs further studies and a survey of experiments from other countries worldwide in dealing with biosolid as an organic source of nutrients to enrich the soil textures of edible plants.

Table 26: Comparison between the Discovered Concentrations of Pollutants and the Acceptable Levels of WHO/FAO.

Pollutants	Levels of tested parameters of Bio-solids		WHO/FAO maximum acceptable levels in Tomatoes mg/kg
	5 Kg Bio-solids	7 Kg Bio-solids	
Zinc (Zn) mg/kg	137.82	112.71	1.5
Cupper (Cu) mg/kg	274.13	260.72	2.00
Manganese (Mn) mg/kg	53.77	43.32	5.00

References; (EPA 1997), (TOYOFUKU and KASUGA 2003)



Line graph 2: Differences Between the discovered concentrations of pollutants and the acceptable levels of WHO/FAO

2. Conclusion

The experiment has fully analyzed and described Qatar's bio-solids of Class A. Sampling was based on specific time intervals of three months between each sample. The biosolid's temporal characteristics (chemical and physical) came out with very promising results in terms of stability, with slight variations recorded among the samples. The physical analyses highlighted that the form of pellets complied with the specified pellets size, with some deficiencies in the odor treatment unit, which can be considered a minor defect. Furthermore, the chemical analysis of parameters like pH, electrical conductivity, organic matter content, among others, were either complying with the local, regional, and international standards or even below the proposed levels. At the same time, investigating the level of nutrients like Nitrogen and Phosphorus illustrated the richness of the product to be suitable for use as an organic fertilizer or soil amendment. In addition, the levels of heavy metals as the main pollutant indicated a significant value well below international levels. Spectrometry revealed no detection of several major metals (e.g., Mercury, Cobalt and Cadmium). Relatively, the remaining values of the other heavy metals were even lower than the American EPA standards of exceptional quality sludge. Based on these results, biosolids are benign for use as an organic fertilizer or soil amender in landscaping projects. This can be attributed to the processing technology using the Swiss combi treatment method. The Doha North Sewage Treatment Plant [DNSTP] was designed to adapt as an efficient technology in managing the biosolids' physical properties, dryness, pellets' particle size, and the levels of pollutants and nutrients. Furthermore, Interpretation for the outputs of using biosolid as an organic fertilizer for tomato production reflected an extraordinary growth and development of plants (*Solanum Lycopersicum*). The plots fertilized with two different rates of bio-solids; 5 and 7 kg/ m^2 had no substantial variances with the control treatment fertilized with 5 kg/ m^2 of cow manure and 20 Ls/ m^2 of peat moss. Most of the plant characteristics revealed non-significant differences between the examined rates of biosolids and manure at the stems, leaves, and fruits. However, the chemical analysis of fruits indicated high concentrations of heavy metals in tomatoes, which goes higher than the acceptable levels for human consumption specified by the World Health Organization (WHO) and food and agriculture organizations (FAO) of the United Nations. Results highlighted the efficiency of bio-solids as an organic fertilizer. Analysis of the plant characteristics of three treatments reveals fundamental information. There was no significant difference in plants' height, fruit densities, stem girth, leaves length and width, and fruit size perimeter for all the treatments. Nevertheless, there was a significant difference in the analysis of the dry matter of all three experiments. Chemicals analysis of the three treatments also provides reliable information that can be used to make informed decisions. There were no significant differences for total Nitrogen, Boron, Calcium, Magnesium, Manganese, Phosphorus, and Potassium. On the other hand, there were significant differences between Copper and Zinc. The main problem with the use of bio-solids in the production of tomatoes is the existence of traces that exceed the required limits, making them poisonous for human consumption. For instance, excessive accumulations of heavy metals' traces such as Zinc, Manganese, and Copper in tomato fruits are toxic to humans. Nevertheless, this biological importance in fertilizing plants cannot cover the toxic impacts of these minerals. It confirmed the unsuitability of Qatar's bio-solids to be used to fertilize tomato fruit as the residues of heavy metals represent an essential risk on health and might turn this popular and commonly used fruit into a cause of cancer due to the harmful effect of these minerals to the human body. Similarly, it ends the potential usage of the human excreta treated in the Doha North Sewerage Station Plant to fertilize edible plants unless significant changes in the treatment methodology take place to minimize the presence of these toxic minerals the produced bio-solids, which is not applicable for now in Qatar.

General Conclusion

The experiments have fully assessed the quality of the produced biosolid in Qatar through an in-depth analysis and checking of the most important chemical and physical characteristics of Class A biosolid to enable users to apply the best agricultural practices depending on the biosolid quality and the optimum application rate. The first experiment tackled the nature of the product itself. It analyzed and described Qatar's bio-solids of Class A's temporal attributes to assess the produced biosolid's quality. The physical analyses highlighted that the form of pellets complied with the specified pellets size, with some deficiencies in the odor treatment unit, which can be considered a minor defect. At the same time, investigating the level of nutrients like Nitrogen and

Phosphorus illustrated the richness of the product to be suitable for use as an organic fertilizer or soil amendment. This can be attributed to the processing technology using the Swiss combi treatment method. The Doha North Sewage Treatment Plant [DNSTP] was designed to adapt as an efficient technology in managing the bio-solids physical properties, dryness, particle size of pellets, and the levels of pollutants and nutrients. Based on the results' outputs, bio-solid approved its richness in both macro and micronutrients by recording the highest levels in contents of total nitrogen, phosphorus, and potassium among the treatments. The same can be said concerning the level of salinity from investigating the electrical conductivity in all treatments. The second experiment discussed the effect of the governmental dosage of 5 kg/m2 in soil against several textures of manure plus peat moss, agrochemical fertilizers of NPK and other trace elements and the control treatment of soil only with the presence of *Petunia atkinsiana* plants as indicators. The experiment analyzed the plants' characteristics resulting from each texture to evaluate the product in the soil following the specified rate. Moreover, complete chemical analysis of soil took place to assess and compare the level of nutrients and pollutants and compared the pollutant heavy metals in soil fertilized with 5 kg/sqm of bio-solid with the acceptable international ceilings of these pollutants in soil. Results approved that the produced bio-solid is very benign to be used as an organic fertilizer without any adverse environmental impacts. The short life cycle of the seasonal Petunia might not give sufficient evidence as this industrial form requires a more extended period to be thoroughly homogenized and melted with the soil to function as a good source of nutrients. Nevertheless, the tested plants' clear acceptable and overall health condition can be an explicit approval of the bio-solids positive role as a fertilizer, which also meets the valuable outputs of the first experiment concerning the quality of the produced bio-solid in Qatar.

The third experiment investigated different application rates to specify the best rate to be utilized and followed. At the same time, it incorporated detailed chemical analysis for soil with indicative plants to assess the best rate by taking a step focused on conducting a chemical analysis of the soil using the three different application rates of 3, 5, and 7 kg/m2 and the control experiment of soil only. Based on the outputs of the results and monitoring process for all these parameters during three months of the seasonal plant's life cycle, the study highlighted that the biosolids proved to be one of the best organic fertilizers for ornamental plants, while the application rates of 5 kg/m^2 and 7 kg/m^2 being successful in developing plants' vegetative growth and flowering in a better and benign way. In conjunction with the analysis of plant characteristics, the chemical analysis revealed promising results regarding the level of nutrients such as nitrogen, phosphorus, potassium, and heavy metals. By contrast, the highest discovered level was well below the regional and international allowable limits, as highlighted in the discussion and comparison tables, which eventually suggest confidently that the levels of 5 and 7 kg/m^2 of biosolids are efficient and safe rates of application to enrich the Qatari soils. The other targets of this experimental design were to investigate the potential impact of all tested application rates on groundwater by analyzing the soil leachates. A further part of this study focused on the leaching behavior of pollutants and nutrients in biosolids adjusted to different rates. Furthermore, the chemical analysis of parameters like pH, electrical conductivity, organic matter content, among others, were either complying with the local, regional, and international standards or even below the proposed levels. At the same time, applying the biosolid to fertilize tomato took place to trial it on edible plants. Investigating the level of nutrients like Nitrogen and Phosphorus illustrated the richness of the product to be suitable for use as an organic fertilizer or soil amendment. Most plant characteristics revealed non-significant differences between the examined rates of biosolids and manure at the stems, leaves, and fruits. However, the heavy metals in fruits were higher than the internationally acceptable levels, making biosolid unsuitable for edible plants production. Nevertheless, further enhancement of the production process and additional studies can manage these significant defects. In a nutshell, results highlighted the efficiency of bio-solids as an organic fertilizer for ornamental plants.

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APPENDIX

Appendix 1: Values of K for use in the equation for computing Diameter of Particles in Hydrometer analysis.

Specific Gravity of Soil Particles									
Temperature °C	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01531	0.01505	0.01481	0.01458	0.01435	0.01414	0.01394	0.01374	0.01355
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01420	0.01399	0.01378	0.01358	0.01339	0.01321
18	0.01474	0.01449	0.01426	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
19	0.01456	0.01431	0.01408	0.01386	0.01365	0.01345	0.01326	0.01307	0.01289
20	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
21	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01275	0.01258
22	0.01404	0.01381	0.01358	0.01337	0.01316	0.01297	0.01278	0.01260	0.01243
23	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01263	0.01246	0.01229
24	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
25	0.01357	0.01334	0.01312	0.01292	0.01272	0.01253	0.01235	0.01218	0.01201
26	0.01342	0.01319	0.01298	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
27	0.01327	0.01305	0.01283	0.01263	0.01244	0.01225	0.01208	0.01191	0.01175
28	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01194	0.01178	0.01162
29	0.01298	0.01276	0.01255	0.01235	0.01217	0.01199	0.01181	0.01165	0.01149

Appendix 2: Table of Temperature factors (f_t) for correcting resistance and conductivity data on Fertilizer extracts to the standard temperature of 25 °C. (Horwitz, Chichilo and Reynolds, 1970)

C	F	t	C	F	t	C	F	t
.0	**7.4**	**.709**	**2.0**	**1.6**	**.064**	**9.0**	**4.2**	**.925**
.0	**9.2**	**.660**	**2.2**	**2.0**	**.060**	**9.2**	**4.6**	**.921**
.0	**1.0**	**.613**	**2.4**	**2.3**	**.055**	**9.4**	**4.9**	**.918**
.0	**2.8**	**.569**	**2.6**	**2.7**	**.051**	**9.6**	**5.3**	**.914**
.0	**4.6**	**.528**	**2.8**	**3.0**	**.047**	**9.8**	**5.6**	**.911**
.0	**6.4**	**.488**	**3.0**	**3.4**	**.043**	**0.0**	**6.0**	**.907**
.0	**8.2**	**.448**	**3.2**	**3.8**	**.038**	**0.2**	**6.4**	**.904**
0.0	**0.0**	**.411**	**3.4**	**4.1**	**.034**	**0.4**	**6.7**	**.901**
1.0	**1.8**	**.375**	**3.6**	**4.5**	**.029**	**0.6**	**7.1**	**.897**

2.0	**3.6**	**.341**	**3.8**	**4.8**	**.025**	**0.8**	**7.4**	**.894**
3.0	**5.4**	**.309**	**4.0**	**5.2**	**.020**	**1.0**	**7.8**	**.890**
4.0	**7.2**	**.277**	**4.2**	**5.6**	**.016**	**1.2**	**8.2**	**.887**
5.0	**9.0**	**.247**	**4.4**	**5.9**	**.012**	**1.4**	**8.5**	**.884**
6.0	**0.8**	**.218**	**4.6**	**6.3**	**.008**	**1.6**	**8.9**	**.880**
7.0	**2.6**	**.189**	**4.8**	**6.6**	**.004**	**1.8**	**9.2**	**.877**
8.0	**4.4**	**.163**	**5.0**	**7.0**	**.000**	**2.0**	**9.6**	**.873**
8.2	**4.8**	**.157**	**5.2**	**7.4**	**.996**	**2.2**	**0.0**	**.870**
8.4	**5.1**	**.152**	**5.4**	**7.7**	**.992**	**2.4**	**0.3**	**.867**
8.6	**5.5**	**.147**	**5.6**	**8.1**	**.988**	**2.6**	**0.7**	**.864**
8.8	**5.8**	**.142**	**5.8**	**8.5**	**.983**	**2.8**	**1.0**	**.861**
9.0	**6.2**	**.136**	**6.0**	**8.8**	**.979**	**3.0**	**1.4**	**.858**
9.2	**6.6**	**.131**	**6.2**	**9.2**	**.975**	**4.0**	**3.2**	**.843**

9.4	6.9	.127	6.4	9.5	.971	5.0	5.0	.829
9.6	7.3	.122	6.6	9.9	.967	6.0	6.8	.815
9.8	7.6	.117	6.8	0.2	.964	7.0	8.6	.801
0.0	8.0	.112	7.0	0.6	.960	8.0	00.2	.788
0.2	8.4	.107	7.2	1.0	.956	9.0	02.2	.775
0.4	8.7	.102	7.4	1.3	.953	0.0	04.0	.763
0.6	9.1	.097	7.6	1.7	.950	1.0	05.8	.750
0.8	9.4	.092	7.8	2.0	.947	2.0	07.6	.739
1.0	9.8	.087	8.0	2.4	.943	3.0	09.4	.727
1.2	0.2	.082	8.2	2.8	.940	4.0	11.2	.716
1.4	0.5	.078	8.4	3.1	.936	5.0	13.0	.705
1.6	0.9	.073	8.6	3.5	.932	6.0	14.8	.694

1.8	**1.2**	**.068**	**8.8**	**3.8**	**.929**	**7.0**	**16.6**	**.683**

Appendix 3: Determination of Heavy Metals in Tomato Plant (Chemists, 2003)

Element	Reagent	Grams	Dissolving reagent
Boron (B)	H_3BO_3	5.7192	H_20
Calcium (Ca)	$CaCO_3$	2.4973	6M HCl
Copper (Cu)	Pure metal	1.0000	HNO_3
Potassium (K)	KCl	1.9067	H_2O
Magnesium (Mg)	$MgSO_4.7H_2O$	10.1382	H_2O
Manganese (Mn)	MnO_2	1.5825	6M HCl
Phosphorus (P)	$NH_4H_2PO_4$	3.7138	H_2O
Zinc (Zn)	Pure metal	1.0000	6M HCl

Appendix 4: Preparation of Standard Solutions below (Chemists, 2003).

	Standard Solution 1		Standard Solution 2	
	Stock	Final	Stock	Final
Element	Solution, ml	Concentrated, mg/ml	Solution, ml	Concentrated, mg/ml
Boron (B)	0	0	10	10
Calcium (Ca)	5	5	60	60
Cupper (Cu)	0	0	1	1
Potassium (K)	5	5	60	60
Magnesium (Mg)	1	1	20	20
Manganese (Mn)	0	0	10	10
Phosphorus (P)	5	5	60	60
Boron (B)	0	0	10	10

Appendix 5: Table Of Operating Parameters for each relevant element as below (Chemists. 2003)

Element	Wavelength, A (nm)
B (CAS-7440-42-8)	2496 (249.6)
Ca (CAS-7440-70-2)	3179 (317.9)
Cu (CAS-7440-50-8)	3247 (324.7)
K (CAS-7440-09-7)	7665 (766.5)
Mg (CAS-7439-95-4)	2795 (279.5)
Mn (CAS-7439-96-5)	2576 (257.6)
P (CAS-7723-14-0)	2149 (214.9)
Zn (CAS-7440-66-6)	2138(213.8)