An-Najah National University

Faculty of Graduate Studies

ASSESSMENT OF RED WIGGLER WORMS ABILITY IN VERMICOMPOSTING OF TREATED SLUDGE, AND COMPARATIVE ANALYSIS OF THE PRODUCED VERMICOMPOST

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This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Environmental Sciences, Faculty of Graduate Studies, An-Najah National University, Nablus, Palestine.

2025

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Dedication

First of all, praise be to God.

Thanks to my beloved homeland, Palestine.

To the souls of the martyrs.

To the prisoners who are in prisons.

To my dear parents for their love, giving and prayers.

To the first supporter who held my hand in reaching success, to my companion, my beloved husband, Yazan Odeh.

To the most beautiful gifts of God, my beloved children, Maryam and Zain.

To my beloved brothers and sisters who stand by my side.

To my second family, my husband's family.

To my father-in-law, may God have mercy on him.

To my wonderful adviser who supervised my thesis, Dr. Abdel Fattah Hasan.

To my friends who encourage and support me.

And to everyone who helped and encouraged me despite the challenges and difficulties I dedicate this research.

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Acknowledgments

I am very grateful to my supervisors, Dr. Abdel Fattah Hasan, for his support, assistance, and encouragement. And Dr. Eldon R. Rene for his support and guidance

I want to thank MEDRC and the Palestinian Water Authority for funding my thesis work.

Thanks to the National Center for Agricultural Research, represented by Muhammad Abu Eid, Director General of the National Center, and in particular, Engineer Muhannad Al-Haj Hussein, for his assistance and supervision of the conduct of the experiment at the Center.

I would also like to thank my husband, engineer Yazan Odeh, for facilitating my work in obtaining sludge from his workplace at the Waste water treatment Plant.

Thanks to the workers at the Waste water treatment Plant in Nablus.

I want to thank my beloved university, An-Najah National University.

I want to thank the laboratory staff at An-Najah National University, especially Engineer Bilal Al-Shayeb.

I want to thank my family.

Declaration

I, the undersigned, declare that I submitted the thesis entitled:

ASSESSMENT OF RED WIGGLER WORMS ABILITY IN VERMICOMPOSTING OF TREATED SLUDGE, AND COMPARATIVE ANALYSIS OF THE PRODUCED VERMICOMPOST

I declare that the work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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Date: 6.2.2025

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ASSESSMENT OF RED WIGGLER WORMS ABILITY IN VERMICOMPOSTING OF TREATED SLUDGE, AND COMPARATIVE ANALYSIS OF THE PRODUCED VERMICOMPOST

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Abstract

Sludge is produced during the wastewater treatment process. It contains organic materials and elevated concentrations of nutrients. So, it is considered a source of pollution. Therefore, further treatment is required to eliminate pollutants in sludge before safe reuse. This study aims to assess the impact of using vermicompost, that produced by feeding red wiggler of Eisenia fetida species on treated sludge and its effect on the growth of basic fodders. Red wiggler, 2000 worms, were brought from and used to treat the sludge produced from Nablus-West Wastewater Treatment plant (WWTP), and produce vermicompost. Two fodder crops were grown, barley and vetch, each crop was planted in 27 pots, 9 of with vermicompost, 9 with sludge and 9 without additives. The study was conducted by the National Agricultural Research Center (NARC) from June 2022 to April 2023. Results indicated that vermicomposting reduced the heavy metal content in the sludge by 45.9% on average, with a range of 7.9% in Na and 83.1% in Mg. According to Palestinian regulations, the original concentration of heavy metal in the treated sludge was below the maximum allowed levels. The analysis of plant growth parameters revealed the highest values in soils amended with sludge, followed by vermicompost, with no significant differences at the 95% confidence level. The fresh weights of barley were 124.7 g/plant, and 113.4 g/plant were for sludge and vermicompost consequence compared to 82.8 g/plant for the control. For vetch, the fresh were 62 g/plant for sludge and 57.6 g/plant for vermicompost. A similar increase in the other plant parameters was found without significant differences. Also, the crops added to vermicompost and sludge showed improved water use efficiency (WUE) compared to those grown without any additives. The (WUE) (kg/m^3) increased from 13.9 to 20.96 for barley with sludge and 19.05 for barley with vermicompost, from 7.05 to 15.18 for vetch with sludge, and 14.10 for vetch with vermicompost. Results indicate that red wiggler worms could be used in vermicomposting treated sludge, and using the resulting vermicompost as soil amendment enhances the production.

Keywords: Earthworms, Plant nutrients, Sludge, Soil amendments, Soil fertility, Vermicompost.

Chapter One

Introduction and Theoretical Background

1.1 General background

The global demand for water for all purposes is increasing continuously due to population growth, activities, and changes in livelihood standards.

According to the United Nations World Water Assessment Programme (WWAP) (2018), by the year 2050, there will only be enough clean water for about 6 billion people. This is a result of the tremendous growth in population and economy that is driving an increase in water demand, a decrease in available water supplies, and an increase in water pollution. This amount may be underestimated, and the shortage of safe water may be far worse (Boretti & Rosa, 2019). Clean water supports human livelihoods, achieves sustainable development, and preserves ecosystem health. The supply of water in acceptable, secure quantity and quality at the location of use is a prerequisite for all essential human activities, including the production of crops and livestock, product manufacturing, the production of electricity, and home tasks (Van Vliet et al., 2017).

The use of water will produce contaminated water. Sagasta et al. (2015) refer to wastewater as contaminated water from human activities. Moreover, this increase in population growth is accompanied by the increase of built-up areas, generating more quantities of municipal wastewater. However, the collected wastewater differs in the collection scale and the treatment level (Jones et al., 2021).

Treating wastewater is a basic need as it is a source of pollution. Therefore, the wastewater is collected and treated in municipal treatment plants to reduce pollution. Many treatment plants have been built in Palestine to reduce the pressure on fresh water and solve the problem of water shortage.

As a byproduct of the treatment process, the solids sedimented or separated through the treatment are known as sludge. The sludge needs more attention and further treatment to be transformed from a source of pollution to a helpful material. Each day, large quantities of sludge are produced in the treatment plants. The quantities depend on the plant scale.

As sludge is a source of pollution, the treatment plants get rid of it mainly through the disposal in the dumping sites as currently. Sewage sludge is a byproduct of treated wastewater. It comprises organic and inorganic materials, a large concentration of plant nutrients, organic chemicals, and pathogens (Patel, 2018).

The water availability is combined with the increasing and growing demand for food supply. The food demand is growing over time due to population growth. This demand forms pressure to enhance agricultural production to meet the demand and reduce the gap between demand and supply. In other words, there is a need to ensure food security. Meeting the food requirement without depleting natural sources is one of humanity's main challenges. To meet the growing demand for food, a viable strategy has been to irrigate water-scarce, rain-fed lands to increase and improve production (Beltran-Pea et al., 2020).

Palestine is located in a semiarid region and suffers from severe water shortage due to a complicated environmental (limited water resources along with the climatic change) and political status (the deny of free access to available sources by the Israeli occupation). The produced wastewater is disposed of either through the collection systems as in the cities or through the cesspits. While there are plans to establish new plants in the cities of Hebron, Tubas, and Nablus East, there are now just a few operational treatment facilities in the West Bank cities. As in Al- Beireh plant, Nablus-West plant, Jenin plant, and Jericho plant. However, the dispersal of residents in built-up areas makes it challenging to establish central treatment plants. According to 2015 estimates, there are 557 localities living in Palestine, 524 of whom are in the West Bank (WAFA, 2015).

Globally, wastewater treatment plant produces about 45 million tons of sewage sludge (Zhang et al., 2017).

The Palestinian experience of sludge treatment is very limited. Many treatment plants in the West Bank produce sludge in large quantities, it estimated 42 g of dry matter per day which are transferred to landfills for dumping (PWA, 2014).

These huge quantities of produced sludge are forming an environmental and economic source of problems. For example, the Nablus- (WWTP) produces 15 tons per day of digested sludge with an approximate moisture content of 70 %. The sludge produced by treatment plants is transferred to a landfill in Jenin for dumping (Abu Ghosh et al., 2021).

The Palestinian legislation principally allows the reuse of sludge after treatment. In contrast, the obligatory technical regulations (T.R. 59-2015), which have legal power, were issued and approved by the Council of Ministers, allowing the reuse of treated sludge. At the same time, the available highly restricted Palestinian standards inhibited the reuse of sludge. Treated sludge reuse is restricted. It requires pre-implantation according to the obligatory technical regulations (T.R. 59-2015), which prevent the use of sludge before treatment.

Red wiggler (*Eisenia foetida*) is an earth Worms species used in composting. It does not live inside the earth like other earthworms but underneath damp plant leaves and decomposed organic matter. It does not live deep inside the earth (Pocock, 2008).

The use of earthworms to reduce sludge is a promising and widespread technology, particularly in small communities in developing countries (Emamjomeh et al., 2018). For this, a potential solution for sludge treatment is transforming the produced sludge into vermicompost used in agriculture.

Vermicomposting is a well-known influence in sewage sludge treatment, which can help minimize the severe environmental issues brought on by its disposal (Domínguez et al., 2021).

Suthar & Singh (2008) reported the potential use of vermicompost in reducing the contaminates in domestic wastes and converting them to nutrients without harming the environment. Therefore, the produced vermicompost from feeding the worms on the produced sludge can contribute to reducing pollution and, at the same time, enhance agricultural production and reduce food insecurity.

1.2 Study objectives

The study is implemented aiming to achieve the following objectives:

- To examine the ability of red wiggler worms to transform sludge into vermicompost.
- To assess the impact of reused treated sludge generated from the Nablus treatment plant on plant growth and production.

- To compare the effects on plants resulting from treated sludge with vermicompost and without any addition.

Overall, this research contributes to solving the problem of sludge final disposal with a beneficial solution.

1.3 Study hypothesis

In this study, the basic assumptions are:

- Red wiggler worms can treat sludge from the sewage treatment plant and transfer it into compost as an additional treatment.
- This vermicompost is of good quality, which makes it safe to be used for plants, and it enhances the production parameters.
- The reuse of treated sludge has no negative impact on the plants. Moreover, they have similar results of natural compost marketed in the local market and the vermicompost produced through the red wiggler worms.

1.4 Literature Review

1.4.1 Introduction (water Introduction Palestine)

Water is the cornerstone of life and a precondition of civilization's existence. All the old civilizations in the middle east were born close to water bodies (Valipour et al., 2020). Water demand is increasing severely due to continuous population growth, changes in consumption patterns, and economic development and growth (WWAP, 2018). The water demand increased more than eight times in the past hundred years from 500 km^3 to approximately 4000 km^3 (Wada et al., 2016). Moreover, it is estimated that the water demand will increase by 20 – 30% by the year 2050, which is enough only for 6 billion humans (Boretti & Rosa, 2019). A clean water supply supports human livelihoods, maintains sustainable development, and preserves ecosystem health. The supply of water in acceptable, secure quantity and quality at the location of use is a prerequisite for all essential human activities, including producing crops and livestock, manufacturing products, electricity production, and home tasks (Van Vliet et al., 2017).

Within the next two decades, there will be a huge increase in the demand for water across all three sectors: industry, residential, and agriculture. Although home and industrial demand will increase more quickly than agricultural demand, agricultural demand will still be the highest. Demand growth in industries other than agriculture will outpace the agricultural sector (WWAP, 2018). Agriculture accounts for 70% of the water consumption (Boretti & Rosa, 2019). At the same time, climate change projections are expected to increase water demand for agriculture (Paymard et al., 2019). In Palestine, 67% of water consumption is for agriculture, with the remaining for domestic and industrial uses (Applied Research Institution of Jerusalem (ARIJ), 2015).

A. Wastewater

This water consumption will produce polluted water, or in other words, wastewater. Sagasta, et al (2015) refer to the wastewater as used or contaminated water that is discharged from different sources as that from houses or agriculture or industry, or other activities, even though the term wastewater is usually related to the contaminated water that is discharged from houses (urban source) through the collecting piping system. Therefore, increased consumption around the globe is accompanied by increased contaminated water production. Both the consumption and wastewater generation are not equally distributed universally, and affected by the water availability. (Sato et al., 2013). Numerous quantities of wastewater are generated daily by the main three water-using sectors: domestic, industry, and agricultural (Ezugbe & Rathilal, 2020). With the continuous population increase the demand on water caused a reduction in quantities of fresh water in agriculture (which was estimated around 70%) under pressure of other sectors, that volume of is consumed by other sectors, and therefore resulted in increasing the generated volume of contamination of water discharged i.e., wastewater (Sato et al., 2013). Wastewater creation is unavoidable because it is necessary in every sector of life's value chain. For example, every barrel of petroleum processed in the oil processing industry, approximately 1.6 cubic meters of wastewater are produced, however the change of water quantities allocated affected the water available for agriculture which is the main sector consuming water. This change is resulted by increasing the daily generation of wastewater by different sectors (Ezugbe & Rathilal, 2020).

In the Middle East region, which already suffers from shortage in water supply for different sectors (Ezugbe & Rathilal, 2020), 23 billion m3 of urban and industrial wastewater are produced annually. Despite the apparent benefits, few comprehensive wastewater treatment plants are companies with reuse initiatives or integrated projects or programs of reuse in agriculture. In most of the Mediterranean region's countries, the main problems include improper treatment, illegal discharges of untreated raw wastewater into the environment, minimal reuse of treated effluents, a lack of innovation, improper operation and maintenance, and a lack of locally available expertise (Stefanakis, 2020). Seawater intrusion (resulted from the region's groundwater discharge in a rate exceeding the recharge) participated in degradation of ground water quality. Degradation of groundwater quality is also a result of contamination from industrial, agricultural, and residential processes. The poor sewage coverage in the majority of the region's countries further exacerbates the issue. The majority of the nations in the region have insufficient sewage coverage, which exacerbates the issue (Stefanakis, 2020). In addition, most sewage networks are found in major urban areas. At the same time, septic systems and cesspits are used in rural or remote places, participating in polluting the groundwater resources. Because of this, the region's rural and isolated districts lack access to sewerage systems or rely on tanker trucks to transport their effluent to the closest treatment plant (Aleisa & Al-Zubari, 2017).

Treating wastewater is needed to reduce the negative impact of untreated wastewater discharge into the environment. Jones, et al. (2021) reported that wastewater treatment aims to reduce pollutant levels under minimum requirements for purposeful reuse or to lessen the environmental effects of wastewater return flows; wastewater treatment tries to improve the quality of utilized water sources, in the same time it reduces the level of contamination to be under sectorial standards, and it is a non-conventional water source. When there is a drought, recovered wastewater effluents are a significant source of water flow for maintaining streams and rivers, and can participate in reducing the pressure on fresh or tap water, where wastewater reuse may be defined as the fortuitous or occasional presence of treated or recovered water in water supply system, that is suitable for the use in the targeted sector (Jones et al., 2021).

However, the wastewater sources highly affect the properties of the influent or characteristics. Wastewater from institutions, such as hospitals and schools, and domestic wastewater, or wastewater from homes, are examples of wastewater from society. Wastewater from industry, intrusion into sewers, Septic tank wastewater/

sludge, landfill leachate, and storm water are examples of external sources while, internally produced

Wastewater includes thickener supernatant, digester supernatant, Discard water following the dewatering of sludge, water draining from sludge dehydrating bedrooms, Water for filtering, water for cleaning equipment (Volcke et al., 2020).

The wastewater coming from municipal uses is the most prevalent form of wastewater that belongs to the low-strength waste stream group, which is municipal wastewater. It has a high amount of particle organic matter and a low organic strength. Municipal wastewater treatment facilities can produce net clean energy (Sikosana et al., 2019). At the same time, industrial wastewater is more concentrated with different compositions.

Zhang, et al. (2019) reported that the chemical industry in China produces high quantities of wastewater with higher toxicity, organic matter, and salinity and that chemical industry wastewater has poor biodegradation (Zhang et al., 2019).

The characteristics of the incoming influent and the reclaimed effluent are essential in the required treatment technology. At the same time, both properties directly impact both the receiving natural water bodies and the reuse of treated wastewater (Sun et al., 2016). Anaerobic systems are appropriate for treating extremely strong wastewaters (biodegradable Chemical Oxygen Demand) COD (concentrations greater than 4000 mg/L), whereas aerobic systems are generally best suited for treating weak strength effluents (COD concentrations below 1000 mg/L). When treating influents at greater concentrations than the cross-over values, the benefits of anaerobic treatment exceed those of aerobic treatment. Additionally, anaerobic treatment typically uses less energy and has the potential to recover nutrients and bioenergy. However, aerobic systems remove more soluble biodegradable organic matter than anaerobic systems do, and the biomass they create is often well flocculated, which lowers the concentration of suspended particles in the effluent. Consequently, an aerobic system's effluent quality is often greater than an anaerobic system's. It is evident that the technique to be used depends heavily on the quality of the influent, such as municipal wastewater, and the targeted quality to be achieved (Sikosana et al., 2019).

The raw wastewater is composed mainly of organic carbon in organic compounds and molecules, and nutrients such as Nitrogen and phosphorus (Guven et al., 2019; Zaman et al., 2019; Arora et al., 2020). In addition, the raw wastewater is a source of different microorganisms, such as bacteria, fungi, and viruses (Xu et al., 2020). These microorganisms include Antibiotic-Resistant Bacteria (ARB) and genes (Tiirik et al., 2021). However, it is reported that raw wastewater is the preliminary source of many diseases (Sharma et al., 2017).

Treated wastewater is an essential nonconventional source of water. Besides its high nutritional content, treated wastewater can decrease the strain on fresh water and even replace mineral fertilizers. As reported by Lahlou et al (2021).

B. Wastewater in Palestine

Palestine It is located in the arid to semi– arid region. It is one of the Middle East and North Africa (MENA) countries, where most of these countries have scarce freshwater resources. In addition to the limited resources. Its difficult political conditions make the water status worse. The complex situation in which the Israeli occupation controls the majority of its natural water resources makes it a water-scarce as well (Hamdan et al., 2022). Due to this combination of environmental and political status, freshwater availability to the Palestinians is limited. The Israeli occupation controls more than 87% of the Palestinian water resources, leaving the Palestinians with access to around 13%. (World Bank Group, 2018; Salem et al., 2021; Qorom et al., 2023). The Palestinian's estimated per capita water share is 73 l/d (Salem et al., 2021), while the per capita annual allocated water is 82 cubic meters (World Bank Group, 2018). Hamdan, et al (2022) reported that approximately 139.6 million m^3 of water the withdrawal quantity of water in the West Bank in 2011, with 88.3 million m^3 going to household uses and the majority of the remaining (51 million cubic meters) being utilized in agriculture.

The generated wastewater is estimated at around 175.5 million cubic meters (Palestinian Central Bureau of Statistics (PCBS), 2019). ARIJ (2015) estimated the produced wastewater in the Palestine to be around 115 million cubic meters; among this, 66 million cubic meters is generated in the West Bank, and the remaining is generated in the Gaza Strip. This volume is expected to be around 237 million cubic meters per year, according to the World Bank (2018).

According to Nashashibi & Van Duiil (1995). Directly after the establishment of the Palestinian national Authority, and due to water shortages, home water usage is relatively low, resulting in highly concentrated effluent identical to industrial wastewater. Even if all of the water that reaches the effluent is of the domestic variety, the COD for one city in the Occupied Territories had a value exceeding 3,670 mg/l (Nashashibi & Van Duijl, 1995; Yaqob, 2016). This is confirmed by Hamdan et al. (2022), who reported that around 60% of West Bank residents did not have sanitary services. There is no connection to a public sewage network, and around 5% of the community is not linked to a potable network (Hamdan et al., 2022). Mizyed & Mays (2020) reported that Palestine lacks the necessary technological, economic, and political infrastructure to reuse wastewater. Some recently built wastewater treatment facilities offer the chance to improve freshwater resources and meet rising water demands. Unfortunately, only a few wastewater treatment facilities—most started operating after 2000—are now in use. As a result, numerous metropolitan areas, notably the major cities of the West Bank, including Jerusalem, continue to release significant amounts of untreated wastewater into the environment (Mizyed & Mays, 2020).

Qorom, et al. (2023) analyzed raw wastewater from the discharge source at different distances. They reported that pH is 5.6 ±0.7, salinity (ECe) 4.20±0.40 dS/m, and organic matter is 7.70±0.65% in the area close to the source. In addition, they reported the existence of many parasite species in the raw wastewater (Qorom et al., 2023). At the same time, Driaat (2020) reported different levels of heavy metals in the same area's raw wastewater resulting from industrial facilities in the industrial zone in the eastern Nablus area. Some of these heavy metals are toxic such as cadmium (Cd) and lead (Pb) at low concentrations, while others are essential for human health at certain concentrations such as Zink (Zn) and Cupper (Cu).

Different studies reported different values of biological oxygen demand (BOD). (BOD) values indicate the quality of W.W. in the West Bank range of 400 mg/l up to 1,400 mg/l, with an average value of roughly 600 mg/l (Salem et al., 2021). In other countries, the (BOD) is (200-300 mg/L), which is low compared to the biological demand in Palestine, which is (400-1400 mg/L), due to the low water consumption per capita in the occupied Palestinian territories due to the political restrictions imposed by the Israeli occupation authorities on Palestinian water consumption, and therefore the resulting wastewater is highly concentrated. (Salem et al., 2021).

C. Sludge & treated sludge

Different words determine sludge or the residual biosolids, but at the same time refer to the solids produced through the wastewater treatment process. Peccia & Westerhoff (2015) explained the sludge formation as they reported that. The effluent water quality is significantly improved by domestic wastewater treatment, which employs physical removal and biological modification of sediments, pathogens, organic compounds, and nutrients. The material separated during a primary settling phase and the settled biotics organisms produced during biological treatment processes after secondary clarification are called "wastewater sludge", the major secondary product of the treatment process. This is close to Dentel & Qi (2014) definition of sludge. They reported that separated substances during the treatment process are not a solution but an intensification of the contamination problem. In some contexts, these materials are called sludges or biosolids (Dentel & Qi, 2014). This definition is close to what was reported by Singh & Agrawal (2008). Who reported that sewage undergoes a number of procedures during treatment that lower the levels of organic components that break down readily. Biosolids, also known as residential wastewater residuals or sewage sludge, are the insoluble solid residue left over after sewage treatment. One of the biggest environmental issues facing the globe today is the secure removal of sewage sludge (Singh & Agrawal, 2008). Therefore, sludge is a term that could be defined as the solids existing or produced as a result of the treatment process of wastewater.

The sludge as a source of pollution is well recognized. Several choices for disposal have been tried: incineration, landfilling, dumping at sea, and soil application. The most cost-effective ways to dispose of sewage sludge are landfilling and land application (Singh & Agrawal, 2008). Werther & Ogada (1999) reviewed the work on sludge treatment and disposal, and reported that the four sludge disposal techniques are currently in use: incineration, landfilling, dumping into marine, and recycling in agriculture. (Werther & Ogada, 1999). About 50% of the sludge is used in agriculture to reclaim land and at the same time disposing of the sludge which is a concern (Collivignarelli et al., 2021).

In addition, Werther & Ogada (1999) discussed the different thermal treatment technologies used for sludge treatment. Kroiss (2004) reported that sludge composition is very close to the composition of treated wastewater. And the composition of both to the chemical composition of raw wastewater, which resulted from both domestic and industrial activities of the modernized civilization (Kroiss, 2004). Understanding the chemical structure of sewage sludge before it is applied to land is necessary due to its diverse nature, which is generated at various treatment facilities and varies with the seasons. Sewage sludge properties are determined by the sludge treatment and wastewater treatment procedures. Typically, organic molecules, macronutrients, a variety of micronutrients, heavy and trace metals, organic micropollutants, and microorganisms make up sewage sludge (Singh & Agrawal, 2008).

In addition, the sludge production is estimated about 20–40 kg of dry matter per person /year. Dentel (2014) gives a more detailed approximation as estimated the global sludge production to be around 26 billion kg annually (Dentel & Qi, 2014). In addition, more detailed distribution of sludge production around the world. At the same time, Zeng, et al. (2022) reported an estimation of sludge production of 30 million tons (30 billion kg) (Zeng et al., 2022). However, the volume of produced sludge is related to the wastewater influent, as the sludge percentage is estimated to be 3 – 5% (Zeng et al., 2022). Liang et *al*., (2021) reported the tremendous growth of the production of Metropolitan Sewage Sludge (MSS), which is the byproduct of sewage treatment. For instance, China's daily-generated sludge volume from the treatment plants is estimated to reach 2.09–108 m^3/d in 2020, and the country produces about 60 million tons of MSS annually (Liang et al., 2021).

The sludge mainly comprises organic compounds, inorganic chemicals, and pathogens (Raheem et al., 2018). Gao, et al., (2020) reported that most of the sludge volume is moisture. They reported 98% of the weight as moisture (Gao et al., 2020), while this percentage can reach 99% of the total weight depending on the sources of influent and the season (Liang et al., 2021). This percentage is lowered by dewatering before the usage of sludge, and the final moisture content is related to the type of use, as reported by (Zhang et al., 2018). Sewage sludge's organic components offer advantageous soil conditioning qualities, and its macronutrients are a rich source of plant nutrients (Singh & Agrawal, 2008).

Dissolved Organic Matter (DOM), DOM's role as a regulator to microbial activity during anaerobic digestion is crucial during anaerobic digestion. Because the insoluble substrates can only be accessed by microorganisms after being solubilized to DOM (Xiao et al., 2020). In the first stage, most dissolved organic matter is removed by sorption to other molecules in the sedimentation process. While 20 – 30% is removed after a few days, as reported by (Xiao et al., 2020).

Huge quantities of sludge are disposed to dumping sites (Gao et al., 2020); despite that positively, sewage sludge is abundant in Nitrogen and phosphorus, which serve as fertilizers for agriculture and other agricultural applications (Wickham et al., 2018). This is confirmed by Mancuso, et al. (2022), who reported that a variety of nutrients found in treated sludge, primarily Nitrogen, phosphorus, and potassium, support its long-term use in agriculture (land-spreading, compost production), as well as environmental requalification measure. Sewage sludge, however, can contain various contaminants, including pathogens, organic pollutants, heavy metals, and other developing contaminants, which are hazardous to crop production and public health if they are not properly handled (Mancuso et al., 2022). According to Romanos, et al. (2019), treated sludge application in agriculture for the fertilization of crops provides the crops with 88% of calcium, 74% of Nitrogen, 73% of phosphorus, and 35% of potassium of the total nutritional requirements (Romanos et al., 2019).

Sewage sludge commonly contains heavy metals such as zinc, lead, cadmium, chromium, copper, and nickel, which cause problems for soil and plant health (Olejnik, 2024). Wang, et al. (2021) assessed the risk of sludge use in agriculture in Taiwan. They reported the risk of trace elements existing in sludge. Therefore, the sludge generated from industrial activities is not recommended to be used.

D. Vermicompost

Vermicompost is derived from converting organic wastes into compost. According to Blouin, et al. (2019). Earthworms employ vermicomposting to turn organic waste products into compost that may be used as a growing medium for plants (Blouin et al., 2019). Previous studies have focused on this treatment, as the use of earthworms to remove or degrade pollutants can be considered one of the most promising bioremediation options (Shi et al., 2020). According to Vuković, et al. (2021), Vermicomposting is a method of biotechnology for composting a variety of organic waste that uses particular species of earthworms that improve the waste's conversion into the end result, which is called vermicompost (Vuković et al., 2021).

Several years ago, many farmers, in an effort to reduce fertilizer use, tried to produce an aqueous extract of vermicompost. These liquids are called teas, as liquids are easier to handle and apply to crops than solids (Arancon N. et al., 2007).

The use of both vermicompost and vermicompost tea in agriculture is well known. They are essential in organic farming for improving soil fertility, nourishing crops, and preventing illness. By significantly increasing microbial biomass, the use of vermicompost as additives and soil fertilizers aids in preserving and restoring agricultural productivity as well as enriching soil biodiversity. Also, their use significantly contributes to the sustainability of agricultural production (Yatoo et al., 2021). Vermicompost contains nutrients that are readily accessible to plants as the case of phosphorus in the form of phosphates, Nitrogen in the form of nitrates, calcium as soluble calcium, and potassium (Jangra et al., 2019). This is in agreement with the study by (Yatoo et al., 2020). Who explained that the producer vermicompost from the worms is very rich in micro and macronutrients such as phosphorus, calcium, zinc, magnesium, boron, potassium, nitrogen, etc., beneficial soil microorganisms, plant growth promoters and hormones, and hence can be used as an organic fertilizer for healthy plant growth. It can also be used as an alternative to harmful inorganic fertilizers.

According to Usmani, et al. (2019), Vermicompost has been shown to impact plants in various ways, the majority of which are advantageous. Vermicompost is generally regarded as improving plant growth, yield, and quality. Vermicompost encourages the growth of roots and shoots, increases the germination of seeds, and vegetative growth through enhancing leaf area, root establishment, crop yield, nutritional quality, and plant flowering, in addition to having a positive impact on biomass, photosynthetic pigments, photosynthesis, and respiration rates (Usmani et al., 2019).

Physically, soils that have been amended with vermicompost have improved in porosity, aeration, and structure. Chemical parameters such as pH, conductivity, organic matter, and nutrient status have also significantly improved due to the application of vermicompost, which has also improved crop growth and yield. Vermicompost is a long-term source of macro- and micronutrients that plants readily digest. Additionally, bacteria that fix Nitrogen and dissolve phosphorus are present (Yatoo et al., 2020). According to Suthar & Singh (2008), Vermicompost contains significantly more micronutrients than farmyard manure, which leads to improved development and production of the garlic plant (*Allium sativum*) (Suthar & Singh, 2008).

Due to its positive impacts on various soil qualities, compost or vermicompost made from different organic wastes is a crucial agricultural supplement (Zandvakili et al., 2019). Different studies reported the effect of vermicompost on yield. Gichaba, et al. (2020) reported the use of vermicompost in garlic. Yatoo, et al (2021) published that vermicompost is currently well-known for its capacity to produce high crops and has been widely used to cultivate many crops. They also reported that vermicompost could be used as a substitute for chemical fertilizers (Yatoo et al., 2021).

Vermicompost are attractive for agriculture because of their macronutrient composition (N, P, K, organic matter) and particular constituents (humic acids, phytohormones, enzymes), among other factors (plant growth/health, soil health). The substrate's characteristics determine the composition, which is varied (Elissen et al., 2023). Not only the nutrient elements but vermicompost contains plant hormones and enzymes, which promote plant growth ((Aremu et al., 2015; Ruangjanda et al., 2022). In addition, the vermicompost content of humic and fulvic acids enhanced the growth and shortened the life cycle of lettuce (Hernandez et al., 2015).

Vuković, et al. (2021) reviewed the published works on the vermicompost effect on plant growth. They reported the macronutrient content of vermicompost according to different studies. Nitrogen content ranged from 2.0 g/kg D.M. to 23.6 g/kg D.M., depending on the vermicompost origin. While phosphorus was 0.2 to 750 g/kg D.M. (Vuković et al., 2021), Usmani, et al (2019) reported different data. However, they reported vermicompost content in comparison to other sources of compost. This comparison shows a different range of nutrient content, but in general, it is higher than green compost, as shown in table (1) (Vuković et al., 2021).

Table 1

A comparison of vermicompost with other compost sources from

		Pig slurry	Cow slurry	Poultry manure	Green compost	VFG compost	Vermicompost
Dry	Matter	107	92	562	600	700	184-965
Organic	Matter	738	772	740	300	240-340	108-944
Ntotal	(N)	65	43	51	5 --8	13	0.1-45
Phosphate	(P2O5)	36	16	41	2--4	5	1.2-103.5
Potassium	(K2O)	44	59	34	7		0.3-189.6
C/N	ratio*	11.9	16.8	8	18.7		5.5-28.5

Note: Vuković et al. (2021.)

E. Earthworms in vermicomposting

In many terrestrial soil systems, earthworms are a functionally important component and the dominant macrofauna. Because they consume many times of what they weigh daily, their significance in pedogenesis and the formation of soil profiles is clear (Bartlett et al., 2010).

Earthworms that are epigeic and stay in the top soil layer (the few centimeters of upper soil) produce vermicompost by feeding on recently decomposed organic materials. Due to their high litter intake and reproduction rates, the most popular species utilized for vermicomposting are *Eisenia fetida* and *Eisenia andrei* (Arancon & Edwards, 2011). Earthworm activity causes the release of nutrients, which is time and space synced with plant activity. They could help improve nutrient usage efficiency and reduce the hazards of nitrate leaching by establishing small patches (the castings) rich in mineral nutrients (Bertrand et al., 2015). Earthworms are subjected to many restricting factors such as plastic materials in the natural environment. The findings of Sáez, et a. (2022) demonstrated that all of the plastic materials examined adversely affected earthworm mortality and body biomass in terms of morphology. The poor organic matter decomposition in the vermicompost subjected to plastic indicates that the changes seen in the enzymatic functioning of the compost and the biofilm appeared to affect the rate of the earthworms and microorganisms of the materials being used during the vermicomposting process ((Sáez et al., 2022; Liu et al., 2022).

Earthworms & microorganisms collaborate to generate vermicompost, an organic amendment rich in nutrients generated from organic waste. Although earthworms serve as vital participants in the vermicomposting process, microorganisms are responsible for organic matter (O.M). Decomposition (Domínguez et al., 2019). It increases the aeration and dissection of O.M. Earthworms indirectly increase microbial activity and biomass by expanding the surface area accessible to microorganisms, which changes the makeup and organization of microbial communities (Gomez-Brandon et al., 2012).

Earthworm contributions to the vermicomposting process might be separated into two stages. The first is the active phase, in which earthworms consume and digest organic wastes in two distinct phases. The second phase is the decomposition (maturation – like), where through this phase, the active microorganisms break down the elements that the earthworms processed, as reported by (Domínguez et al., 2010).

Similar to composting, vermicomposting includes bio-oxidative reactions and the decomposition of organic waste; the difference is that earthworms and microorganisms interact in vermicomposting. Earthworms participate in an even bigger microbial population by fragmenting and ingesting fresh organic material. At the same time, microorganisms produce enzymes that promote the biochemical degradation of organic matter. Along with the aforementioned, earthworms are also associated with other soil-dwelling creatures. They can have an impact on different microflora and microfauna groups (Kundariya et al., 2021).

During soil remediation, earthworms reduce the concentration of heavy metals. It can build up H.M.s in their bodies. As a result, metallothionein, a protein that can bind various metals, including Zn2+, Cu2+, and Mn2+, is produced (Lv et al., 2016). This is similar to the findings of Liu & Xue. (2012). They reported that when comparing heavy metals content in the vermicompost and the earthworms' tissues, they found that the levels of Cu, Ni, Cd, Pb, and Zn increased inside the tissues, while in the same time, it reduced in vermicompost when compared to the initial sewage sludge. Simultaneously, the total Nitrogen increased (Liu et al., 2012). Controversially, Song, et al (2014) reported an increase in (As, Pb, Cu, and Zn) concentration in vermicompost. This increase resulted from the organic degradation process of materials containing these elements during composting (Song et al., 2014). While (Zigmontienė & Liberytė, 2014) confirmed in their study that vermicomposting using the worm (*Eisenia fetida*) reduces the concentration of heavy metals in the sludge, especially Ni, Cd, and Cr. These findings confirm that the final concentration of these heavy metals depends on the original composition of the source, where the mobility and availability are affected by the chemical characteristics of the compounds, not the total content (Lv et al., 2016).

In their review, Dhakane & Shinde (2020) reported the morphology and taxonomic features of the earthworms of *E. fetida.* Indeed, there is a wide difference in the taxonomy of these two species between the different taxonomic scientists. Despite this disagreement, many researchers consider *E. fetida* and *E. andrei* unique species. *E. fetida* is known as a “brandling” or “tiger” worm, while *E. andrei* is known as red worms (Dhakane & Shinde, 2020). Some studies have indicated that both worms are identical and have a very similar life cycle and live in the same environment, so it is possible that hybridization may occur between them, these types of worms are the most widely used types for organic waste management, due to their availability all over the world, their short life cycle, and their ability to adapt to temperatures and humidity. They are flexible earthworms that can be easily handled (Dominguez et al., 2005). Both species are shown in figure (1)

Figure 1

Species of earthworms that used to producing vermicomost

Note: A- E. Andrei the common "red" worm. B- E. fetida its common names of "brandling" or "tiger" earthworm.

In figure (1). The red wiggler worms are growing on organic wastes as such as sawdust, kitchen scraps, vegetable plants residues, pig, horse, camel, sheep, and goat manure from cattle ranches, as well as sierozem soil are used with E. Andrei (A), and *E. fetida* the common “red” worm (B). Grown during an experiment that was conducted in Kazakhstan (Abdimutalip, 2014)

A valuable review of the use of earthworms in vermicomposting is that of Emamjomeh et al. (2017). After reviewing the studies related to the use of earthworms and aquatic organisms, they reported that *Eisenia fetida*, *Eisenia andrei*, *Eudrilus eugen- iae, Perionyx excavatus*, and *Perionyx sansibaricus* are identified as potential aquatic worms that are used in organic waste material decomposition. In addition, they reported the advantages of these species in reducing the heavy metal content and their positive impact on plant growth.

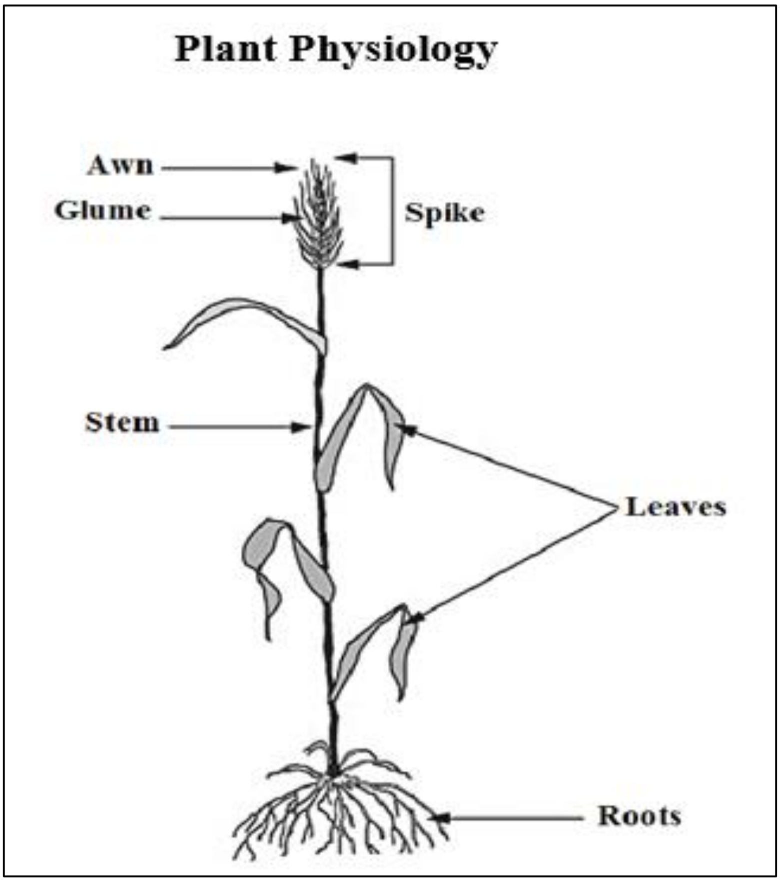
F. Barley

Hordeum vulgare, known as barley, is one of the ancients' cereal crops grown today, included in both human diets and animal feedings (Biel et al., 2020). It is an annual grain crop of the *Poaceae* (formerly known as *Gramineae*) family. This family includes the most important grain crops, such as wheat barley as a family member is one of the monocotyledons (Campbell, 2023; Gupta, 2023). Barley's ability to adapt to arid conditions made it a basic crop, which facilitated the transition from foraging to agriculture in the region (Fall et al., 2002).

Gleason (2019) gives a detailed description of the different stages of barley crop. Through this description are the different parts of the plant (figure 2) with a definition of each part.

Figure 2

A detailed barley plant parts (from Gleason, 2019)



In animal feeding, the part of the plant consumed depends on the type of feeding. The grains are barley fed as part of the feeding concentrate. In contrast, the remaining above-ground parts (the stem and attached leaves) are used as filling fodders. Among other advantages, these minerals may improve heart health, lower inflammation, and aid in the fight against cancer (Kubala, 2019). The relative content barley is shown in Table (2) .

Although it is mostly used for brewing and as animal feed, barley is also regarded as a staple food in areas where other major grains cannot be cultivated (Giraldo et al., 2019). Not only to animals but barley consumed through human diets. Barley offers vitamins, minerals, and fiber as a whole grain. However, because they barley have an abundance of non−starch polysaccharides (NSP), the carbohydrates in barley are not as quickly broken down as those in maize. Usually, 65–70% of the carbohydrates in maize grains come from starch, while 11–14% come from fiber. Levels of non-starch polysaccharides in maize fiber are modest (Jacob & Pescatore, 2012).

Table 2

The nutritional value of barley per 100 g

Nutrient	Hulled barley	Pearl barley
Energy calories	354	352
Protein (g)	12.5	9.9s
Fat (g)	2.3	1.2
Carbohydrate (g)	73.5	77.7
Fiber (g)	17.3	15.6
Calcium (milligrams [mg])	33	29
Iron (mg)	3.6	2.5
Magnesium (mg)	133	79
Phosphorus (mg)	264	221
Potassium (mg)	452	280
Sodium (mg)	12	9
Manganese (mg)	1.9	1.32
Selenium (micrograms [mcg])	37.7	37.7
Folate (mcg)	19	23

Note: from Kubala (2019).

Many factors affect the nutritional content of barley; it was reported that under the combined influences of cultivar-specific features, meteorological conditions, and agricultural technique, barley grain's chemical content and nutritional value significantly change (Biel and Bashutska, 2018). Tobiasz-Salach et al. (2018) showed the differences in grain size and other production elements of four cultivars responding to foliar fertilization.

G. Vetch

Vetch (*Vicia sativa* spp) is a robust annual legume typically used as a cover crop that fixes Nitrogen. It is a winter crop and one of the legume family (Fabaceae (*Leguminosae*)).

Common (or hairy) vetch, a grain legume, is used in animal feeding. It has a high protein, fatty acid, and mineral content, making it a particularly suitable ingredient to supplement feedstuff. Like other legumes, the common vetch can fix atmospheric Nitrogen, which is essential for developing sustainable agricultural systems. These characteristics make vetch a better choice for intercropping systems and as a cover crop in addition to its use as fodder (Ramírez-Parra & De la Rosa, 2023).

Vetch is widely planted in the temperate and Mediterranean region, and it is one of the favoured fodder crops (Francis et al., 2000). As a result of the ongoing climate changes, there will be a strong need for legumes as common vetch (Vicia sativa), which thrive in marginal agricultural zones, are drought resistant, and resilient to variable yearly weather patterns (Nguyen et al., 2020).

Due to its greater drought tolerance, the common vetch can thrive in vulnerable cropping zones and is resistant to changing yearly weather patterns. According to Tenopala, et al (2012), Vetch could endure a water shortage for up to 24 days before fully recovering its biotic activity. In response to increasing temperatures worldwide and lengthening droughts caused by climate change, drought and heat-tolerant crops are becoming increasingly popular.

H. Barley and Vetch in Palestine

Barley & Vetch are among the most planted and oldest fodder crops in Palestine. Their importance is due to the fact that they are two basic crops that supported early agriculture and contributed to the development of agriculture. These two crops are planted as rainfed crops. Barley is fed as grains to animals, in addition to its hey. Vetch is fed as dry or green hey. According to the data of the national agricultural census, the area of barley and vetch form 33% of the area planted with fodders, barley is around 22% and vetch is around 11%. The area of land planted with barley in Palestine is about 5069 m^2 while the area of land planted with vetch is about 2569 m^2. Knowing that the area of land planted with fodder crops in Palestine is 23064 m^2. (Palestinian Central Bureau of Statistics (PCBS), 2019).

Chapter Two

Methodology

2.1 Experimental design and conditions

The experiment was conducted in (NARC) in Jenin and Nablus-(WWTP) near Beit Leid village from June 2022 to April 2023.

The experiment comprises two stages: the production of vermicompost from the treated sludge by red wiggler worms of *Eisenia fetida* species. The second stage is planting two fodder crops.

2.2 Source of worms

Worms were purchased and raised in a suitable medium with suitable temperature and humidity, in addition to providing them with food to ensure their survival and reproduction. After several weeks of raising the worms, sludge was gradually added to them.

at first, during the month of June 2022, were contacted an organic farm called Um Suleiman Farm to buy worms, which is a farm specializing in raising and selling 2000 worms, as they are raised in a suitable environment with a temperature of 20-25 °C and high humidity of 70-90% was provided. After obtaining the worms, were taken care of, and within two days worms were transferred to the National Agricultural Research Center to live on peatmoss soil in plastic containers and provided with food to ensure their survival and reproduction. This type of worms reproduces quickly and prefers darkness and humidity, and feeds on simple uncooked foods such as carrots, food scraps and eggshells.

2.3 Source of sludge

The sludge was obtained from the Nablus-West Wastewater Treatment Plant. The produced sludge is treated through anaerobic digesting in mesophilic digesters that produce biogas in the treatment plant. The produced treated sludge has a high moisture content (70%) (Abu Qaud & Alhaj Hussein, 2019). Solar drying dewaters the treated sludge to reduce the moisture content.

10 kg of sludge with 70% moisture content was transported from the Nablus West Wastewater Treatment Plant to the experimental site at the research center in black plastic bags at intervals and at the center the solar drying was completed to reach 10% moisture content. It is worth noting that the Nablus treatment plant is the only plant in the West Bank that has a biodigester that stabilizes the organic content of the biologically nutritious sediments and produces biogas. Other treatment plants do not have this feature, and the resulting sludge is within the specifications in Palestinian technical regulations 2015 (Abu Qaud & Alhaj Hussein, 2019).

Sludge was gradually added to the worms After three months of raising, caring for and reproducing it.

2.4 Obtaining vermicompost

After three weeks of adding the sludge to the worms, vermicompost is formed, which can be obtained by exposing the worms to light, which leads to hiding in the soil, then scraping the vermicompost material, which is mixed with twice its amount of water, and then using a press we obtain the vermicompost material. After collecting the vermicompost, it is used in agriculture by adding it to the soil before planting.

2.5 Cropping condition

Barley and vetch, which are fodder crops, were selected for the experiment. The two crops were planted in plastic pots with a surface area of (0.09 square meters) at the (NARC) on 8/1/2023. A drip irrigation system was installed. These pots were distributed according to (complete random design). The number of seeds planted in each pot was calculated by measuring the weight of 1000 seeds for each crop separately, as barley seeds weighed 50 g per 1000 seeds, while vetch seeds weighed 15 g per 1000 seeds. Therefore, the number of seeds inside each pot was calculated based on the density of field plants according to farmers' practices such as:

- Barley at 13 g/m^2 (1.17 g/pot). Which is equivalent to 23 seeds
- Vetch at 15 g/m^2 (1.35 g/pot). Equivalent to 90 seeds.

With continuous monitoring and continuous watering, the seeds grew on 17/1/2023 in all pots.

2.6 Treatments

The planting experiment is composed of three treatments with nine replicates for each treatment, which are:

- Planting in soil mixed with treated sludge
- Planting in soil mixed with vermicompost produced by red wiggler.
- Control

The overall methodology is shown in the flow chart at the appendix (B).

In Summary, the steps that were followed in experimenting are:

The growth environment is inside plastic containers filled with washed sawdust to eliminate chemical effects from the wood processing. In the first three months, the worms were fed with readily decomposed organic materials to ensure the stabilization and growth of the worms. Feeding on treated sludge started after three months by feeding the worms on the treated sludge (10% moisture content).

The vermicompost was obtained by exposing the worms to light that caused them to hide in the soil and then scraping off the vermicompost material. When both the vermicompost and the sludge were added to the soil, they were mixed well with the soil before planting. It is worth noting that the process of producing compost using worms took three weeks and that the worm produced about half its weight in vermicompost (Manyuchi & Phiri, 2013).

Figure 3

Red wiggler worms inside plastic containers

The resulting compost was analysed for its content and nutritional value.

Tow fodder crops (Barley and Vetch) were planted in sludge-mixed soil, vermicompost-mixed soil, and soil without additives.

A total of 54 plastic pots with 8 liters volume were used. Nine pots for each treatment were planted with each crop. The mixing rate for treated sludge and vermicompost was 10% of the total volume (0.8 litre sludge or vermicompost per pot).

Plant growth was monitored during the growing period by continuous weekly visits and whenever attendance was required, the most important of these visits is the time to bring the worms and prepare the plastic containers for them, then visit the wastewater plant to bring the sludge and transport it to the (NARC) and start drying it, collecting the vermicompost and then preparing the containers for planting after mixing the soil with the sludge and vermicompost and then planting the crops, in addition to subsequent visits to monitor the plant growth and take the necessary data, and the following plant information was collected: plant growth rate, fresh weight at cutting time, number of spikes for barley, length of roots, number of flowers for vetch.

Figure 4

Preparing for planting and monitor the plant growth and take the necessary data

Note: A- Preparing pots for planting. B- Measuring plant length.

The plants in the two treatments (sludge and compost) are irrigated with equal water during the experiment. The irrigation requirements were calculated based on the FAO – Penman Montieth formula.

2.7 Parameters monitored

The following plant parameters were measured:

The plants were measured directly in the field, it was in the final growth stages (kernel hardening for barley and, vetch after full seeds in pods)

2.7.1 Fresh weight

Is calculated in the harvest season by cutting the plant and measuring its weight when our plant is harvested immediately.

fresh weight includes water content in the plant at the harvest time. Water content can change due to time or environmental conditions, so we need to take measurements as soon as we harvest the plant. Otherwise, we can get inconsistent data, and after recording the readings the average was taken for each treatment.

2.7.2 Dry weight

Is calculated after drying the plants at a temperature of 70 °C for 48 hours, then the average of the data was taken for each treatment.

2.7.3 NPK

The plants content of nutrients (N, P, & K) were measured after harvesting, while the soil content of the same nutrients were measured before planting, the followed analysis method is that of ICARDA procedure (Estefan et al., 2013).

Nitrogen is measured using Kjeldahl method following (Estefan et al., 2013) procedure.

This procedure typically involves the following steps:

- Digestion: Organic nitrogen is converted to ammonium sulfate using concentrated H_2SO_4 and a catalyst mixture to raise the boiling temperature and to promote the conversion.
- Distillation: The ammonium sulfate is treated with NaOH to release ammonia, which is distilled and absorbed in a boric acid solution.
- Titration: The boric acid solution containing ammonia is titrated with standard sulfuric acid to determine the amount of nitrogen.

Potassium is measured following (Estefan et al., 2013) procedure. Via flam photometer analysis.

The procedure includes the extraction through use 5 g of sample and 33 mL of NH4OAc, shake for 5 minutes, and centrifuge. Repeat process and combine extracts to a volume of 100 mL.

Then operate Flame Photometer, Prepare K standards and draw a calibration curve.

Measure K at 767-nm wavelength.

Calculate K concentrations using the calibration curve.

Phosphorus: The content of phosphorus was analysed following (Estefan et al., 2013). Utilizing using Spectro photometric.

The Measurement of Phosphorus include digestion through Weigh 2 g of the sample into a 250-mL calirated digestion tube, and add 30 mL 6 HClO4 in a digestion tube, then heat the mixture, and continue heating until the material becomes like white sand.

The next step is Cool the mixture, bring it to volume, mix well, and filter through Whatman No. 1 filter paper.

Pipette 5 mL of clear filtrate into a 50-mL flask, then add 10 mL of ammonium-vanadomolybdate reagent and dilute to volume with DI water.

Read absorbance at 410-nm wavelength using a spectrophotometer.

Prepare a standard curve and determine the concentration of phosphorus from the curve.

2.7.4 Crop water requirements

The crop water requirements were calculated by using modified FAO – Penman Montieth formula combining the reference evapotranspiration (ETo) with the crop parameters. The calculation was based on the climatic parameter which was collected from the weathering station in (NARC).

The crop water requirements were calculated from the reference evapotranspiration and crop coefficient in different growth stages using CROPWAT 8.0 software.

To calculate (CWR) for barley and vetch, the growth period was determined and each month during the growth period was divided into three specific periods (1, 2 and 3), ten days for each period, and then the growth stages (Ini, Dev, Mid and Late) were determined according to the FAO method on monitoring.

$$ET_{c=} K_c \ x \ ET_o \ldots\ldots\ldots\ldots\ldots(1)$$

Where:

ET_c: crop water requirement (mm/day)
K_c: crop coefficient
ET_o: reference evapotranspiration

2.7.5 The climatic parameters

Is used to calculate the reference evapotranspiration (ET_o) and then the crop water requirement was calculated if using the crop coefficients (Kc).

2.7.6 Organic content.

Organic matter is measured by drying the sample, grinding it into a powder, then weighing a specific amount of the dried sample and recording the value.

The next step is to burn the sample in an oven, which burns away the organic matter, leaving only the inorganic material. The burned sample is then weighed after cooling.

The difference between the pre-burn and post-burn weights is used to calculate the organic matter content.

2.7.7 Plant length.

Plant length was measured for both vetch and barley for all samples by ruler and after recording the readings the average was taken for each treatment.

2.7.8 Root length

After harvesting the plants, root measurements were taken for all samples for both plants by ruler.

2.7.9 Heavy metals content in the plants

Heavy metal tests were conducted on both plants (barley and vetch) in the laboratory of An-Najah National University.

2.7.10 The Water Use Efficiency (WUE)

The water productivity in barley and vetch is calculated during the experiment from:

- Data on irrigation water quantities were supplied to each pot.
- Data on the produced biomass dry weight from each pot.

The diameter of the pot is used to identify the area.

The Sodium Adsorption Ratio (SAR).

SAR was calculated using a specific formula.

The analysis was following ICARDA procedure for analysing plants, water, and soil (Estefan et al., 2013). Some of these parameters were measured in the laboratory of An-Najah National University following the same procedure of analysis, where it was necessary to dry the fodder crops after harvesting and grind them using a special machine in the laboratory and use the samples to conduct tests.

Using the following formula, the (SAR) is a number that reflects the ratio of sodium ions to the total quantity of magnesium and calcium cations in water. All concentrations are given in milliequivalents per liter

$$SAR = \frac{(Na)}{\sqrt[2]{\frac{(Ca)+(Mg)}{2}}} \text{...............(2)}$$

According to the Soil Survey Staff (2017), the ratio of the Na concentration is specifically divided by the square root of half of the Ca + Mg concentration (Soil Survey Staff, 2017).

2.8 Data analysis

The data were collected and tabulated for the analysis. After obtaining all the data from more than one source, where part of the analysis was conducted in the An-Najah University laboratory, part was conducted in NARC, and another part was conducted in other laboratories, and in the end, they were collected in Excel files and prepared for statistical analysis.

2.9 Statistical analysis

The data were collected and tabulated for the analysis. IT was statically analysed by conducting one – way analysis of variations (ANOVA) test, followed by post hoc test to compare between different groups (Kim, 2017). The Statistical Package for the Social Sciences (IBM SPSS) software ver. 26 were used to conduct the analysis for each measured result.

Chapter Three

Results and Discussion

3.1 Climatic data and irrigation crop water requirements and irrigation requirements

Table (3) shows the results of reference evapotranspiration in the experiment site.

Table 3

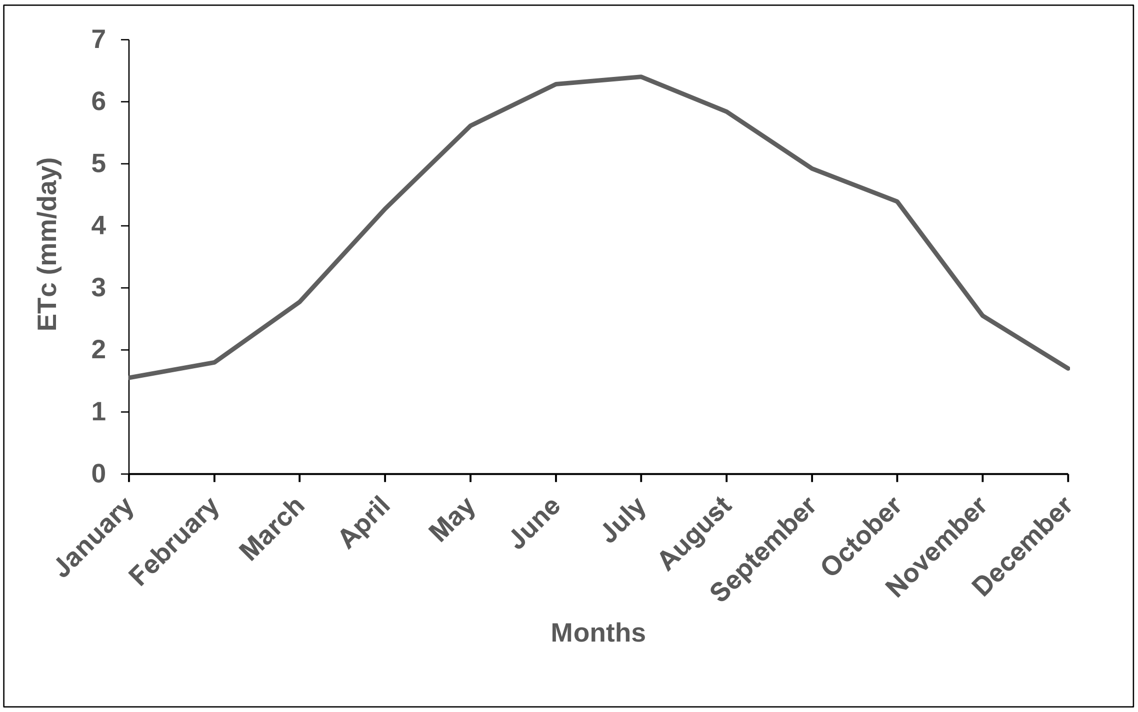
The reference evapotranspiration in Jenin area and the long – term monthly climatic parameters (2023)

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	Eto
	°C	°C	%	km/day	Hours	MJ/m²/day	mm/day
January	6.8	17.4	80	168	5.4	10.3	1.55
February	7.1	18.2	84	178	5.6	12.5	1.8
March	8.6	21.6	76	178	6.8	16.5	2.77
April	11.2	28.3	67	178	7.8	20.2	4.27
May	14	31	60	200	9.7	24.2	5.61
June	17.3	32.9	63	209	11.3	26.9	6.28
July	19.6	33.6	63	218	11.1	26.3	6.4
August	21.1	34.2	65	191	10	23.7	5.84
September	19.8	33.2	64	160	9.1	20.3	4.92
October	16.1	30.6	65	253	8.1	16.1	4.39
November	11.8	25	66	138	6.8	12.1	2.55
December	8.7	18	74	169	5.4	9.7	1.7
Average	13.5	27	69	187	8.1	18.2	4.01

The results show that the maximum (ETo) occurs in July (6.4 mm/day) (Figure 8), while the minimum is in January (1.55 mm/day).

Figure 5

Reference evapotranspiration in Jenin area



The Crop Water Requirements (CWR) are calculated using crop parameters in different growth stages for the two crops, as shown in table (4).

Table 4

The irrigation and the crop water requirement (CWR) for barley and vetch in Jenin area

Crop	Month	Period	Stage	Kc	ETc	ETc	Irr. Req.	
				Coeff	mm/day	mm/period	mm/period	Mm/day
Barley	Dec	1	Init	0.3	0.6	3.6	3.6	0.36
	Dec	2	Deve	0.3	0.52	5.2	5.2	0.52
	Dec	3	Deve	0.54	0.88	9.7	9.7	0.97
	Jan	1	Deve	0.89	1.42	14.2	14.2	1.42
	Jan	2	Mid	1.13	1.75	17.5	17.5	1.75
	Jan	3	Mid	1.14	1.86	20.5	20.5	2.05
	Feb	1	Mid	1.14	1.96	19.6	19.6	1.96
	Feb	2	Mid	1.14	2.05	20.5	20.5	2.05
	Feb	3	Mid	1.14	2.42	19.4	19.4	1.94
	Mar	1	Late	1.08	2.64	26.4	26.4	2.64
	Mar	2	Late	0.8	2.21	22.1	22.1	2.21
	Mar	3	Late	0.49	1.59	17.5	17.5	1.75
	Apr	1	Late	0.28	1.06	3.2	3.2	0.32
Vetch	Dec	1	Init	0.4	0.79	4.8	4.8	0.48
	Dec	2	Init	0.4	0.68	6.8	6.8	0.68
	Dec	3	Deve	0.45	0.74	8.1	8.1	0.81
	Jan	1	Deve	0.67	1.08	10.8	10.8	1.08
	Jan	2	Mid	0.91	1.41	14.1	14.1	1.41
	Jan	3	Mid	0.99	1.62	17.9	17.9	1.79
	Feb	1	Mid	0.99	1.71	17.1	17.1	1.71
	Feb	2	Late	1	1.79	17.9	17.9	1.79
	Feb	3	Late	1	2.13	17	17	1.7
	Mar	1	Late	1	2.45	24.5	24.5	2.45
	Mar	2	Late	1	2.78	27.8	27.8	2.78
	Mar	3	Late	1	3.28	36.1	36.1	3.61
	Apr	1	Late	1	3.78	15.1	15.1	1.51

The results show that the maximum water requirements for barley occur in the first period of March (2.64 mm/day) due to increased air temperature. The crop coefficient is the highest at the end of the growth stage and starts to decrease gradually in the late season stage. For these two reasons, the highest water requirements in the barley experiment resulted in the first period of March.

As the results reveal, the crop water requirements for vetch (218 mm) are higher than those of barley (199.4 mm), and the highest demand is in the third period of March with 3.61 mm/day) in this period. These variations come from differences in the crop characteristics (variations in crop coefficients). However, during the experiment, the irrigation was set to satisfy the plants water requirement as shown in table (4).

3.2 Vermicompost and sludge

The results of sludge and vermicompost analysis (table 5) show a general reduction in the content compared to sludge.

Table 5

Sludge & vermicompost analysis results

Treatment	pH	EC	T N	P	K	Na	O.M	C
		dS/m	%	%	%	Ppm	%	%
Sludge	7.9	1.0	14.6	4.1	6.0	0.0	41.9	71.0
Vermicompost	6.8	0.9	8.9	3.6	4.7	0.0	47.5	76.6

This reduction in pH agrees with many studies, mainly Liu & Zhu (2012). Who reported that pH has reduced from 7.4 to 6.3, in addition Huang (2013) also supported that resulted in significant reductions in pH from 7.03 to 6.20 after using red worms, However, the total nitrogen has decreased in the vermicompost compared to the sludge, while Liu and Zhu have reported an increase in the total and available nitrogen, also in Huang (2013) study the content of total nitrogen increased. This reduction could be referred to the low nitrogen content in the worm's growth media, before supplying the sludge, where it was fed with vegetables residues which are poor with nitrogen. This explanation is supported with the increase in organic matter and carbon content in vermicompost compared to sludge.

3.3 Heavy metals

In the vermicompost, the results of heavy metal analysis show a general reduction in heavy metals content compared to the sludge content table (6). This reduction could be explained by the activity of the red wigglers (Yatoo et al., 2021). According to Abdimutalip (2014), researchers believe that microorganisms present in vermicompost facilitate the conversion of toxic forms in heavy metals into immobile compounds. According to other studies, this decrease in heavy metals led to the accumulation of metals in the worm's tissues (Yadav et al., 2023). At the same time the results showed that the treated sludge content of heavy metal is below the maximum allowed concentrations according to the Palestinian technical regulations (T.R. 59 – 2015) (Palestinian National Authority (PNA), 2015).

According to Palestinian National Authority (PNA), (2015) The maximum permissible limit for cadmium according to the regulations is 20 ppm, and its value in vermicompost is 0.00026 ppm while its value in sludge is 0.0014 ppm, while the maximum limit for lead is 750 ppm and its value in vermicompost is 0.0014 ppm and in sludge is 0.0021 ppm, while for zinc the permissible percentage is 2500 ppm and according to table (6) its value in vermicompost is 0.22 ppm and in sludge is 0.64 ppm, and According to (Suthar et al., 2014) the presence of red worms caused a significant decrease in Cd levels (32–37 %), Cr (47.3–80.9 %), Cu (68.8–88.4 %), and Pb (95.3–97.5 %), and in another study (Huang et al., 2013) reported that the use of red worms in treatment of activated sludge reduced the concentration of heavy metals for Cu, Zn, Pb and Cr by (35.2 - 37.7%), (29.3 - 38.8%), (21.2 - 27.4%) and (17.0 - 23.0%), respectively.

Table 6

Concentration of heavy metals in vermicompost and treated sludge

	Vermicompost	Sludge	
Metal	Conc. Mean	Conc. Mean	Unit
Na	2.3E+01	2.9E+02	Ppm
Cd	2.6E-04	1.4E-03	Ppm
K	1.4E+02	6.3E+02	Ppm
Rb	2.5E-02	1.1E-01	Ppm
Ca	3.8E+01	1.5E+02	Ppm
Cu	2.4E-02	8.6E-02	Ppm
Sr	1.4E-01	4.4E-01	Ppm
Se	7.3E-04	2.2E-03	Ppm
Zn	2.2E-01	6.4E-01	Ppm
Al	9.3E-01	2.7E+00	Ppm
V	7.6E-04	2.1E-03	Ppm
Bi	2.6E-04	5.8E-04	Ppm
Ba	3.9E-02	8.4E-02	Ppm
Ga	7.9E-04	1.7E-03	Ppm
Co	7.3E-04	1.3E-03	Ppm
As	9.7E-04	1.6E-03	Ppm
Mo	1.4E-02	2.2E-02	Ppm
Pb	1.4E-03	2.1E-03	Ppm
Fe	1.7E+00	2.6E+00	Ppm
Ag	9.8E-05	1.5E-04	Ppm
Mn	3.4E-01	5.1E-01	Ppm
Cr	3.7E-02	5.2E-02	Ppm
Li	2.3E-03	3.0E-03	Ppm
Mg	4.1E+01	4.9E+01	Ppm

even though Sludge contains heavy metals, but within the allowed levels permitted by regulations. however, it should be sanitized or treated further for hygienic reasons. According to the study, we noticed a lower value of heavy metals in vermicompost than in sludge such as lead, cadmium, zinc.

3.4 Sodium Adsorption Ratio (SAR)

When the value of (SAR) was calculated, the result was (6.4) for sludge and (0.8) for vermicompost, so the value of (SAR) for vermicompost showed low hazards as the sludge (SAR).

According to Haritash et al. (2014), the hazard from these SAR values is very low. Therefore, no negative impact is expected from using either treated sludge or vermicompost, even though the vermicompost shows further treatment by red wiggler and a reduction of the SAR value.

3.5 Crops physical characteristics

Results in Table (7) show the differences between plants mixed with sludge and those mixed with vermicompost and plants without any addition of grown barley for all physical characteristics. Fresh weight, dry weight, plant length, no. of spikes, and no. of tillers is higher for plants with sludge and vermicompost comparison with control, except for the root length, there is no significant difference between the three treatments.

Table 7

Physical characteristics of barley for the different treatments

Criteria	Treatment	N	Mean	Std. Dev.	Std. Error Mean
Fresh Weight (g)	Control	9	82.78	7.27	2.42
	Sludge	9	124.73	25.63	8.54
	Vermicompost	9	113.36	24.07	8.02
Dry Weight (g)	Control	9	20.17	1.76	0.59
	Sludge	9	30.39	6.25	2.08
	Vermicompost	9	27.62	5.87	1.96
Plant length (cm)	Control	9	51.82	3.66	1.22
	Sludge	9	66.71	8.98	2.99
	Vermicompost	9	65.97	10.21	3.40
Root length (cm)	Control	9	9.52	1.85	0.62
	Sludge	9	10.44	2.00	0.67
	Vermicompost	9	9.38	2.80	0.93
No. of Spikes	Control	9	2.11	0.928	0.309
	Sludge	9	5.67	1.414	0.471
	Vermicompost	9	5.22	1.202	0.401
No. of tillers	Control	9	3.78	1.093	0.364
	Sludge	9	5	1	0.333
	Vermicompost	9	4.67	1.323	0.441

Results in Table (8) show the differences between plants mixed with sludge and those mixed with vermicompost and plants without any addition for all physical characteristics of vetch. Fresh weight, dry weight, plant length, root length, and no. of flowers is higher for plants with sludge and vermicompost comparison with control, except for the root length, there is no significant difference between the three treatments.

Table 8

Physical characteristics of vetch for the different treatments

Criteria	Treatment	N	Mean	Std. Dev.	Std. Error Mean
Fresh Weight (g)	Control	9	28.83	8.42	2.81
	Sludge	9	61.97	12.80	4.27
	Vermicompost	9	57.59	11.54	3.85
Dry Weight (g)	Control	9	6.14	1.81	0.60
	Sludge	9	13.23	2.73	0.91
	Vermicompost	9	12.29	2.46	0.82
Plant length (cm)	Control	9	46.97	3.54	1.18
	Sludge	9	57.63	9.91	3.30
	Vermicompost	9	54.92	8.68	2.89
Root length (cm)	Control	9	9.27	1.86	0.62
	Sludge	9	8.97	1.99	0.66
	Vermicompost	9	7.78	1.69	0.56
No. of flowers	Control	9	1.78	1.641	0.547
	Sludge	9	4.33	1.323	0.441
	Vermicompost	9	4	1.414	0.471

3.5.1 Fresh Weight

Results on the fresh weight table (7 & 8) & figure (6) reveal that crops planted in soil mixed with sludge have the highest fresh weight over those planted in soil mixed with vermicompost or soil alone.

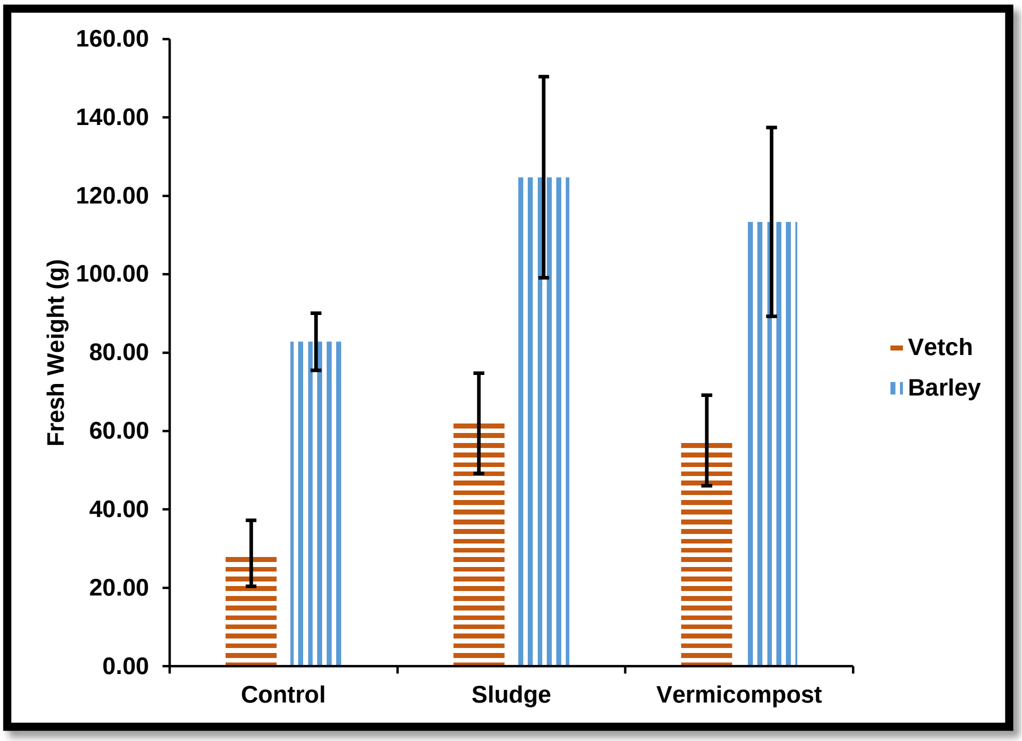
The average fresh weight of barley for sludge treatment is 124.7 g/plant, compared to 113.4 g/plant for vermicompost and 82.8g/g/plant for the control treatment, while in the vetch plant in the soil mixed with sludge have the highest fresh weight 61.97 g/plant, compared to 57.59 g/plants mixed with vermicompost and 20.17 g/plant in those planted in the soil without any addition.

These results show that there are significant differences at a 95% confidence level, as presented in table (A.1) between the three treatments. These differences reveal that between sludge and vermicompost treatments, there are no significant differences in the fresh weight production, while there are differences compared to the control (table A.2) for both barley and vetch.

So, the use of vermicompost increases the fresh weight of both crops, this was confirmed by Abusamra (2022) where the average fresh weight of barley irrigated with treated water was 124.1 g/plant compared to 87.75 g/plant irrigated with fresh water and the same applies to vetch.

Figure 6

Fresh weight production (g/plant) in the three treatments for barley and vetch plants



3.5.2 Dry weight

Results of dry weight show a similar pattern as in fresh weight, where the same trend appears in the dry weight of barley and vetch, as shown in table (7 & 8).

The barley plants in the soil mixed with sludge have the highest dry weight, 30.39 g/plant, compared to 27.62 g/plants mixed with vermicompost and 20.17 g/plant in those planted in bare soil. In vetch plants, the dry weight was 13.23 g/plant in sludge treatment and 12.29 g/plant in vermicompost. These results show significant differences in the dry weight between treatments, as the analysis of variations reveals (table A.3).

However, the dry weight average production in both sludge and vermicompost mixed soils did not significantly differ at 95% confidence level and was significantly higher than the average dry weight in non-mixed soil, as shown in table (A.3).

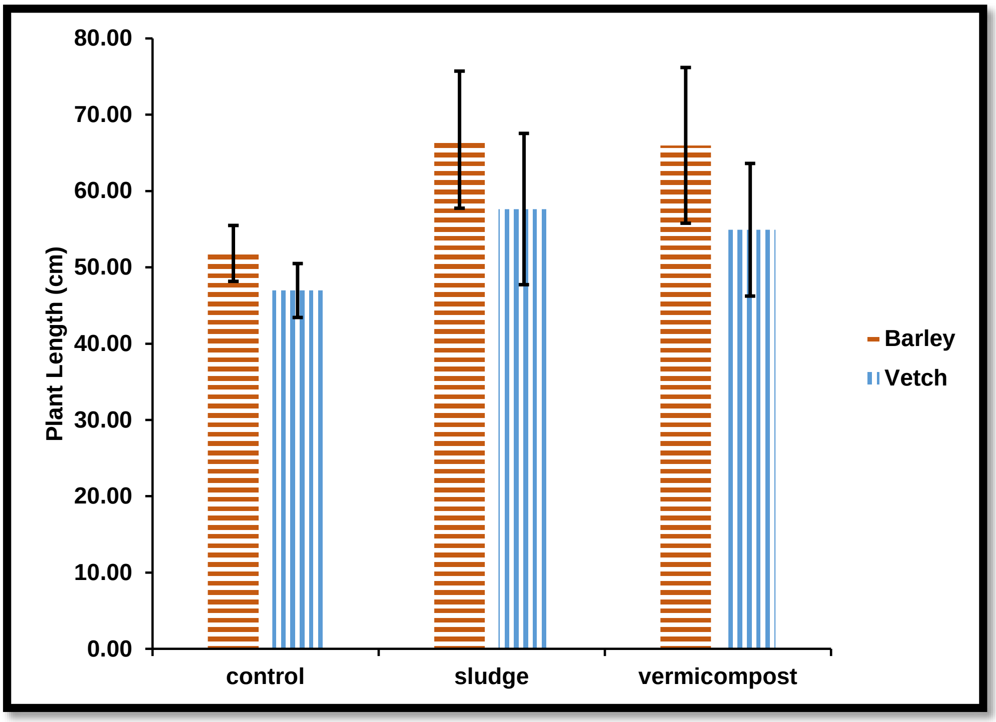
The fresh and dry weight results of this study agree with the findings of different studies (Liu et al., 2012; Tontti et al., 2016). Pasqualone, et al (2017) reported an enhancement in the production (fresh and dry weight) coming from sludge and composted sludge amendment compared to the control with 43% up to 83% depending on the application rate. In this study, barley production increased by 50.5% in both fresh and dry weight, while in vetch, the increase was higher (113 -115%) in the fresh and dry weight. The vermicompost amendment increases the produced weight with 36% in barley and 100% in vetch. These results agree with the report of Pasqualone, et al (2017).

3.5.3 Plant length

Results of plant length have the same trend as weight, where both barley and vetch planted in sludge mixed soil have the highest plant length (table 7 & 8) & Figure (7) with 66.7 cm/ plant in barley and 57.6 cm in vetch. In vermicompost mixed soil, the average plant length was 65.9 cm/plant in barley and 54.9 cm/ plant in vetch.

Figure 7

Average plant length results of different treatments in both barley and vetch plants



The results show the same pattern as fresh and dry weight, where the plant length is significantly higher in both sludge and vermicompost mixed soils (table A.4), but at the same time, there are no significant differences at a 95% confidence level in plant length for those plants in sludge or vermicompost mixed soils.

These results indicate that plant growth is enhanced when soil sludge and vermicompost are amended. This enhancement growth could be referred to the amendment content of nutrients of sludge or vermicompost that resulted in enhanced plant length. The results agree with (Pasqualone et al., 2017).

3.5.4 Root length

The results of root length in the experiment did not reflect the variations in the treatment. As the results show (table 7 & 8), the average root lengths for barley were 10.44 cm and 9.38 cm, respectively, for plants in sludge and vermicompost amendments.

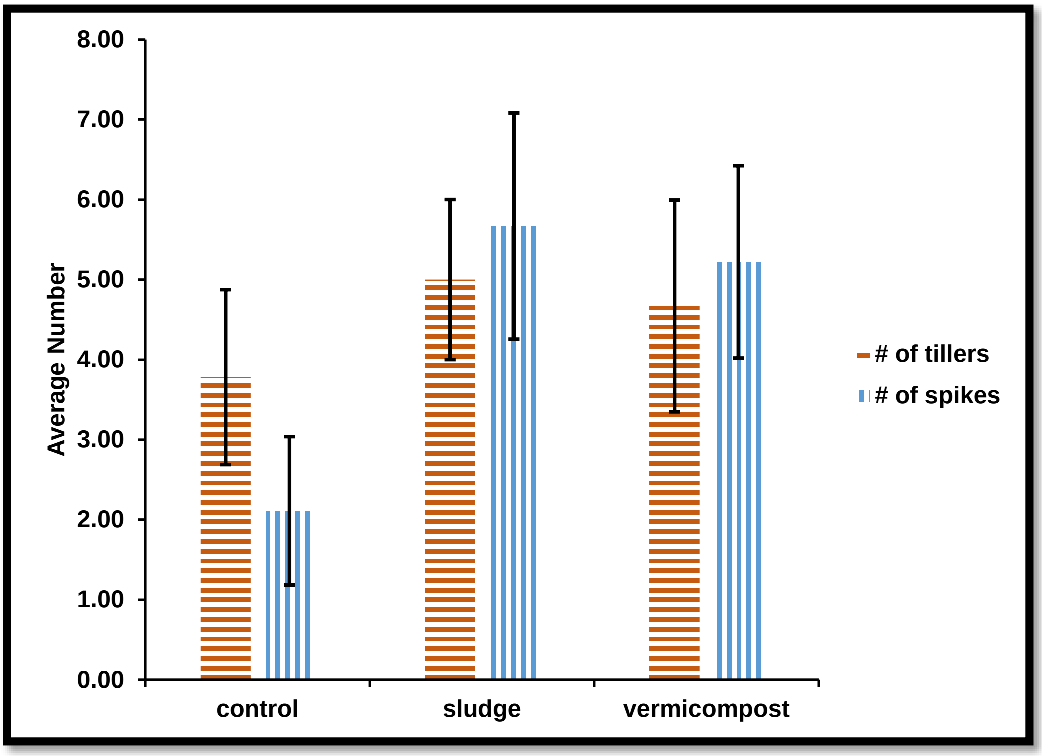
However, these results did not show significant variations in root length under the different treatments (table A.5). This could be explained by the effect of limited space in the pots for root growth. Both barley and vetch plants were grown in pots, as explained in the method and materials. The internal depth of the pots is limited; therefore, the distance for root growth is limited during the growing season.

3.5.5 Number of spikes and number of tillers

In barley plants, the number of spikes and tillers (table 7; figure 5.C) reveals that barley planted in sludge-mixed soils has the highest average number of spikes and tillers per plant (5.67 and 5). While the number of spikes and tillers in barley planted in vermicompost-mixed soils (5.22 and 4.67), compared to the control (2.11 and 3.78) which showed significantly lower values for the number of spikes and the number of tillers.

Figure 8

Average number of (spikes and tillers) in barley plants in different treatments



However, the results statistically show a different pattern table (A.6). The average number of spikes follows a similar trend to the weight as there are significant differences in the number of spikes between the plants in sludge and vermicompost-mixed soils compared to the control. At the same time, there are no significant differences in the number of tillers between the sludge and vermicompost.

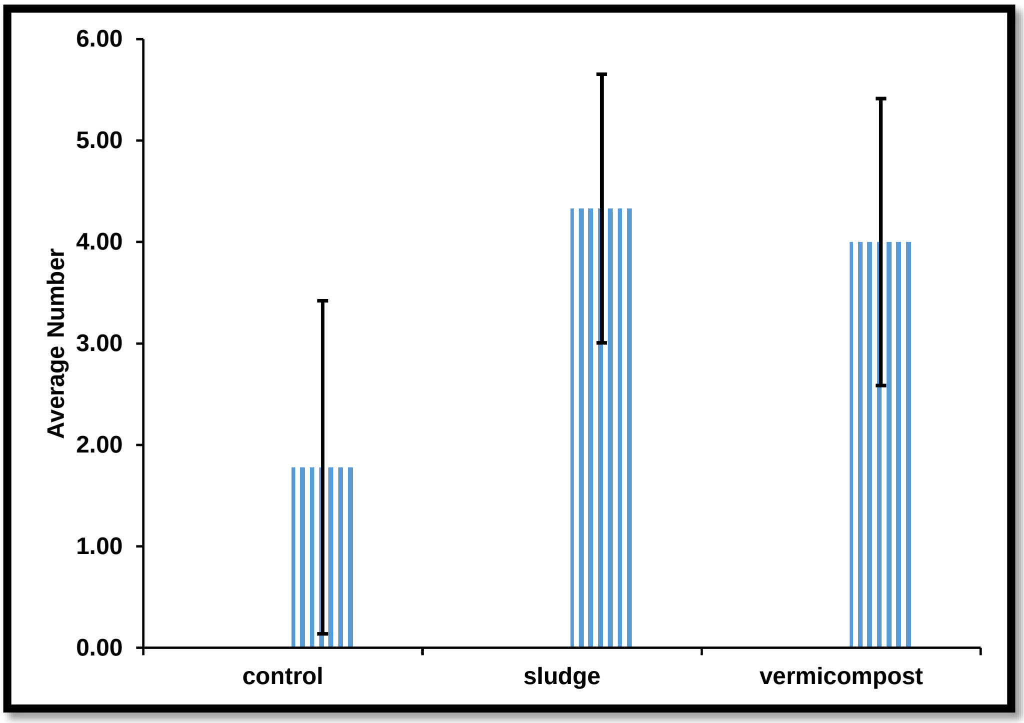
In the number of tillers, the results show no significant differences between the barley plants in vermicompost and those planted in soils without any amendments. At the same time, there are no significant differences in the number of tillers between plants grown in soils with sludge as an amendment and those grown in vermicompost as a soil amendment. These results could be explained by the genetic characteristics of the planted barley strain, as reported by Hussien, et al 2014. Simultaneously, these results agree with Pasqualone, et al 2017 and Abusamra, et al 2022.

3.5.6 Number of flowers

In vetch, the results of the number of flowers follow a similar pattern to that of weight and length, as presented in Table (8; figure 9).

Figure 9

The average number of lowers in vetch plants in the three treatments



As the results show, the highest number of flowers are found in vetch planted in sludge as a soil amendment, an average of (4.33 flower/ plant). In contrast, those planted in vermicompost have an average of (4 flowers/ plant). These results show significant differences in the number of flowers between the sludge and vermicompost compared to the control (soil without amendments), as table (A.7) shows.

The results show significant differences in the number of flowers in vetch plants grown in soils mixed with sludge and soils mixed with vermicompost to those grown in soils without amendments. However, at the same time, there are no significant differences at a 95% confidence level in the number of vetch flowers in plants grown in sludge or vermicompost as amendments. These results indicate the positive impact on the growth and production parameters of vetch when using sludge or vermicompost as soil amendments. Simultaneously, these results agree with ((Jangra et al., 2019; Usmani et al., 2019).

3.6 Water productivity (WUE)

The water productivity in barley and vetch is calculated during the experiment from:

- Data on irrigation water quantities were supplied to each pot.
- Data on the produced biomass dry weight from each pot.

The diameter of the pot is used to identify the area and, as a result, the total irrigation quantity supplied to the plants. The average WUE in both vetch and barley for the different treatments is presented in table (9).

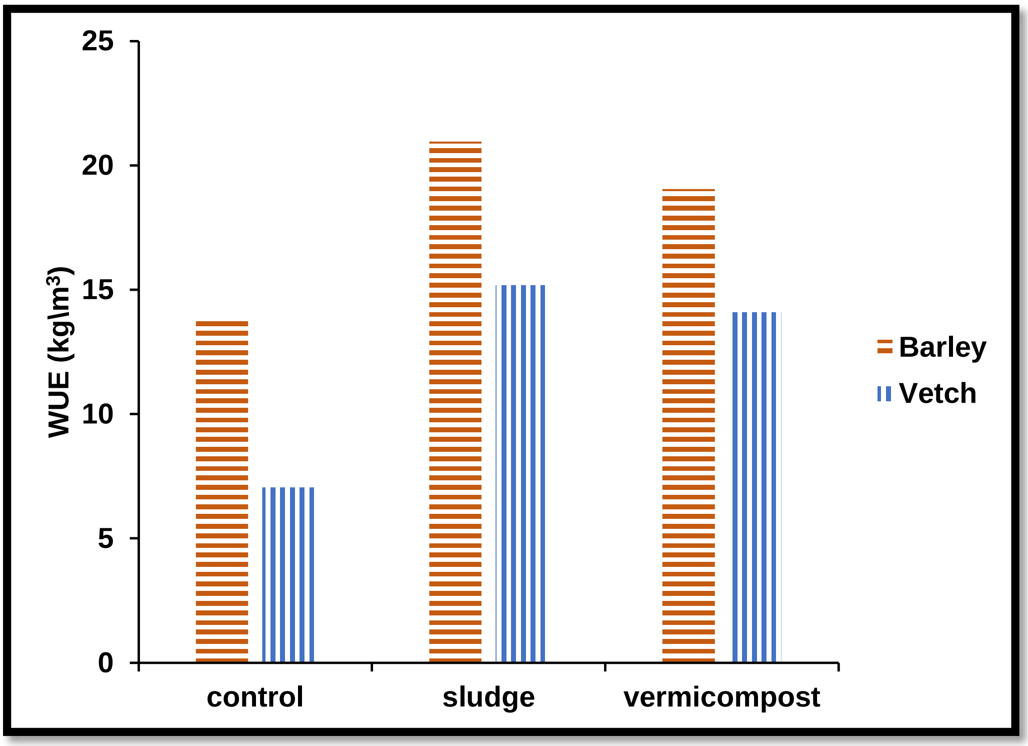
Table 9

The average WUE in vetch and barley for the three treatments (kg/m^3)

	Barley			Vetch		
	Control	Sludge	vermicompost	Control	Sludge	vermicompost
dry weight	20.17	30.39	27.62	6.14	13.23	12.29
CWR (mm)	199.4	199.4	199.4	217.9	217.9	217.9
Water volume (L)	15.95	15.95	15.95	17.43	17.43	17.43
Number of plants	11	11	11	20	20	20
Total weight (g)	221.83	334.28	303.84	122.89	264.67	245.78
WUE (kg/m^3)	13.906	20.955	19.047	7.050	15.183	14.099

Figure 10

The average WUE in vetch and barley in the three treatments (kg/m^3)



As shown in the barley results, the WUE increased from (13.91 kg/m^3) in the soil without amendments to be (20.96 kg/m^3) in the soils mixed with sludge and (19.05 kg/m^3). At the same time, in vetch, WUE in sludge-mixed soils was the highest (15.18 kg/m^3), and (14.1 kg/m^3) in vermicompost mixed soils.

In the vetch crop, the WUE was (15.18 kg/m^3) in sludge compared to (14.1 kg/m^3) in vermicompost and (7.05 kg/m^3) in control. These results reveal that WUE was positively enhanced in the crops due to the effect of sludge or vermicompost.

Results of statistical analysis of WUE (table 9.B) show a similar pattern to the weight and plant length, where significant differences exist between soil without amendment (control) and soil mixed with sludge or vermicompost. At the same time, there are no significant differences in WUE between soil mixed with sludge and soil mixed with vermicompost.

Table 10

LSD multiple comparison of WUE in both barley and vetch for the three treatments

	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.
Barley	Control	Sludge	-7.05-*	1.64	0
		Vermicompost	-5.14-*	1.64	0.005
	Sludge	Control	7.05*	1.64	0
		Vermicompost	1.91	1.64	0.256
Vetch	Control	Sludge	-8.14-*	1.28	0
		Vermicompost	-7.06-*	1.28	0
	Sludge	Control	8.14*	1.28	0
		Vermicompost	1.08	1.28	0.407

These results reveal that the positive effect in WUE comes from the effect of vermicompost and sludge. The results of this study agree with the published results of (Huang et al., 2020; Leakey et al., 2019; Tambussi et al., 2007). However, at the same time, the results of WUE are lower than those of (Abusamra et al., 2022), who reported higher values of WUE for both barley and vetch.

Chapter Four

Conclusions and Recommendations

4.1 Conclusions

In this research, a study on how to reduce sewage sludge that produced in large quantities in treatment plants was conducted. Knowing that sludge contains many organic materials and nutrients that can be used by using red wiggler worms that feed on sludge and produce vermicompost that works to positively enhance production standards, as the results revealed. Two fodder crops were used, barley and vetch, and the soil was fertilized with vermicompost and sludge for comparison.

So, treating sludge using red worms is an effective solution to the problem of its accumulation in purification stations and the problem of the high cost of disposal, as the worms act as an additional treatment to the sludge, as they work to reduce the unflavored content in the sludge.

The most important conclusions of this study can be summarized as follows:

- Vermicomposting is a very effective process, as earthworms convert organic waste by digesting sludge into nutrient-rich vermicompost. The amount of vermicompost produced varies based on several factors, including temperature, humidity, and type of organic waste.
- The conversion of sludge by red worms into vermicompost with rich nutrient content positively enhances the production of barley and vetch.
- The use of red wiggler worms to produce vermicompost helps to get rid of the accumulation of sludge in treatment plants and reduces its quantity, which reduces the costs incurred by treatment plants to dispose of it in landfills. On the other hand, the production of vermicompost, as mentioned previously, enhances the production of barley and vetch, which in turn reduces the pressure on feed and uses it as animal feed in larger quantities and at a lower price.
- The composition of the sludge, including its nutrients and nutritional elements, works to enhance production standards and improve crop growth positively and significantly, as revealed by the results, and it is also within the permissible levels for heavy metals, but from a health perspective, it must be purified or further treated.

- The production under soils mixed with vermicompost sludge, doesn't significantly differ from the production under soil mixed with sludge, as a clear increase was observed in the physical properties of both barley and vetch, there was a clear increase in the fresh weight and the increase in the plants grown with the sludge was higher than the fresh weight of the plants grown with the vermicompost, but there were no clear differences, as well as for the dry weight and plant length.

4.2 Recommendations

Based on the results of this study, some recommendations that may be important for future studies on the subject of sludge treatment using red worms are the subject.

Major recommendations of this research are:

- It is recommended that the activity of earthworms in composting raw and treated sludge under different environmental conditions and sludge compositions be deeply investigated at different moisture content.
- Investigating the effect of using vermicompost and composted sludge in agriculture and the impact on the environment in the short, medium, and long term is recommended.
- Scientific research on different aspects of treating raw sludge and reducing the pollutant hazards under Palestinian conditions is recommended
- It is recommended to study the effect of using vermicompost resulting from feeding red wiggler worms on a larger scale, with different doses.
- It is recommended to study the accumulation of heavy metals in worm tissues in the long term and its impact on the soil.
- It is recommended to study the types of worms most suitable for treating sludge and the optimal conditions for the life of worms.

List of Abbreviations

Abbreviation	Meaning
WWTP	West Wastewater Treatment Plant
NARC	National Agricultural Research Center
WUE	WUE
WWAP	World Water Assessment Programme
ARIJ	Applied Research Institution of Jerusalem
COD	Chemical Oxygen Demand
ARB	Antibiotic Resistant Bacteria
MENA	Middle East and North Africa
PCBS	Palestinian Central Bureau of Statistics
BOD	Biological Oxygen Demand
MSS	Metropolitan Sewage Sludge
DOM	Dissolved Organic Matter
NSP	Non-starch Polysaccharides
O.M.	Organic Matter
PNA	Palestinian National Authority
SAR	Sodium Adsorption Ratio
Eto	Evapotranspiration
CWR	Crop Water Requirements

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Appendices

Appendix A

Tables

Table A.1

Analysis of variations between the fresh weight in the three treatments for barley and vetch

			Sum of Squares	df	Mean Square	F	Sig.
Barley	fresh weight	Between Groups	8474.17	2	4237.08	9.861	0.001
		Within Groups	10312.52	24	429.69		
Vetch	fresh weight	Between Groups	18786.69	2	2915.80	23.79	0.000
		Within Groups	5831.59	24	122.57		

Table A.2

Comparison between the three treatments in fresh weight in barley and vetch

Dependent Variable	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.
Barley	control	Sludge	-41.96-	9.78	0.00
		vermicompost	-30.58-	9.78	0.01
	sludge	vermicompost	11.38	9.78	0.26
Vetch	control	Sludge	-33.13-	5.22	0.00
		vermicompost	-28.76-	5.22	0.00
	sludge	vermicompost	4.38	5.22	0.41

Table A.3

Analysis of variances between the three treatments in both barley and vetch

		Sum of Squares	Df	Mean Square	F	Sig.
Barley	Between Groups	503.20	2	251.60	9.85	0.001
	Within Groups	612.88	24	25.54		
	Total	1116.09	26			
Vetch	Between Groups	266.70	2	133.35	23.84	0.000
	Within Groups	134.25	24	5.59		
	Total	400.95	26			

Table A.4

Analysis of variance in average plant length for the three treatments in barley and vetch

		Sum of Squares	df	Mean Square	F	Sig.
Barley	Between Groups	1266.90	2	633.45	9.59	0.001
	Within Groups	1585.18	24	66.05		
Vetch	Between Groups	553.26	2	276.63	4.46	0.023
	Within Groups	1488.60	24	62.02		

Table A.5

Mmultiple comparisons between the three treatments' root lengths (cm) of barley and vetch plants

LSD						
	Dependent Variable	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.
Barley	root length	Control	Sludge	-0.92-	1.06	0.395
			vermicompost	0.14	1.06	0.893
		Sludge	Control	0.92	1.06	0.395
			vermicompost	1.07	1.06	0.326
Vetch	root length	Control	Sludge	0.30	0.87	0.734
			vermicompost	1.49	0.87	0.101
		Sludge	Control	-0.30-	0.87	0.734
			vermicompost	1.19	0.87	0.185

Table A.6

Multiple Comparisons between the number of spikes and the number of tillers in barley under the three treatments

Dependent Variable	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.
number of spikes	Control	Sludge	-3.556	0.565	0
		Vermicompost	-3.111	0.565	0
	Sludge	Control	3.556	0.565	0
		Vermicompost	0.444	0.565	0.439
number of tillers	Control	Sludge	-1.222	0.541	0.033
		Vermicompost	-.889	0.541	0.113
	Sludge	Control	1.222	0.541	0.033
		Vermicompost	0.333	0.541	0.543

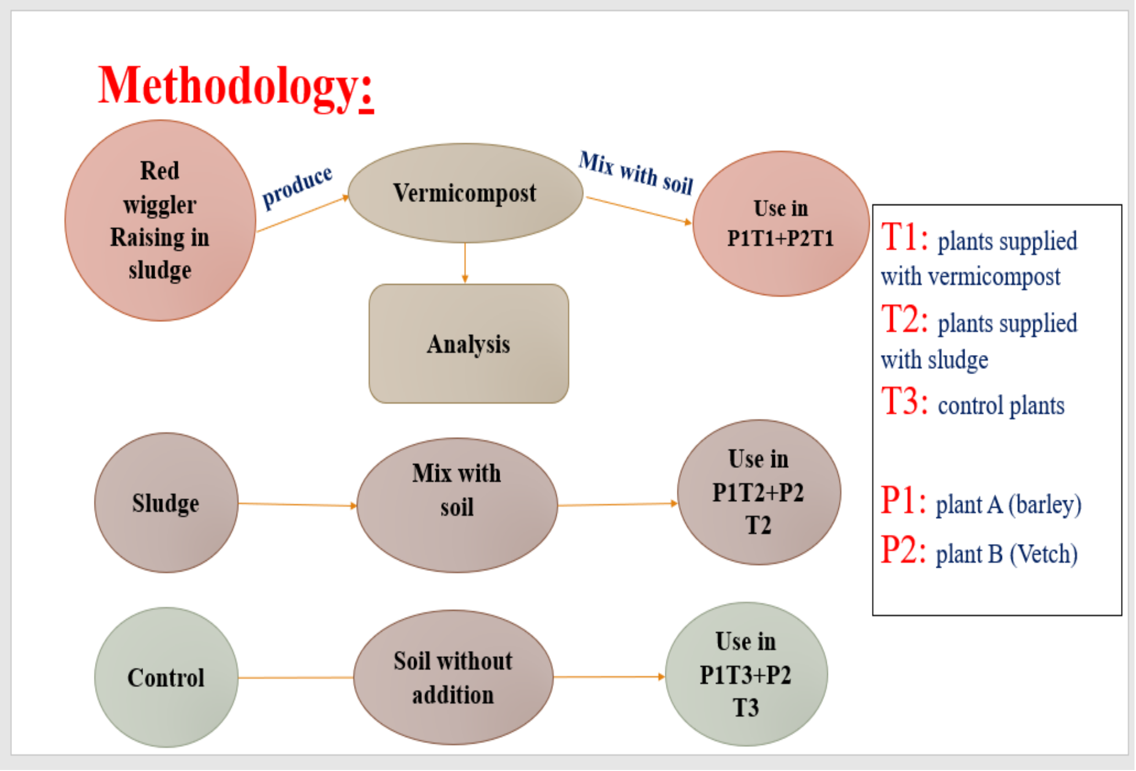
Table A.7

Multiple comparisons between the number of flowers in vetch plants under the three treatments

Dependent Variable	(I) treatment	(J) treatment	Mean Difference (I-J)	Std. Error	Sig.
number of flowers	Control	Sludge	-2.556	0.691	0.001
		vermicompost	-2.222	0.691	0.004
	Sludge	Control	2.556	0.691	0.001
		vermicompost	0.333	0.691	0.634

Appendix B

The overall methodology



جامعة النجاح الوطنية

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الملخص

يتم انتاج الحمأة أثناء عملية معالجة مياه الصرف الصحي. تحتوي علـــى مـــواد عضـــوية وتركيـــزات مرتفعة من العناصر الغذائية. لذلك تعتبر مصدراً للتلوث، لذلك، يلزم إجراء معالجـــة إضـــافية لإزالـــة الملوثات من الحمأة قبل إعادة استخدامها بشكل آمن .تهدف هذه الدراسة إلى تقييم تأثير استخدام الســـماد الدودي، الناتج عن تغذية الدودة الحمراء من نوع *Eisenia fetida* على الحمأة المعالجة وتأثيرها على نمو الأعلاف الأساسية .

تم جلب 2000 دودة حمراء من محطة معالجة مياه الصرف الصحي نابلس الغربيـــة، وإنتـــاج الســـماد الدودي .تم زراعة محصولين من العلف، الشعير والبيقية، زرع كل محصول في 27 وعاء، 9 منها مع السماد الدودي، و9 مع الحمأة و9 بدون أي إضافات .أجريت الدراسة من قبل المركز الوطني للبحـــوث الزراعية (NARC) من يونيو 2022 إلى أبريل 2023 .أشارت النتائج أن التسميد بالديـــدان أدى إلـــى خفض محتوى المعادن الثقيلة في الحمأة بنسبة 45.9٪ في المتوسط، مع نطاق 7.9٪ في الصـــوديوم و 83.1٪ في المغنيسيوم .وفقًا للوائح الفلسطينية، كان التركيز الأصلي للمعادن الثقيلة في الحمأة المعالجـــة أقل من الحد الأقصى المسموح به. أظهرت النتائج أن معايير النبات كانت الأعلى في التربة المختلطـــة بالحمأة المعالجة، تليها التربة المختلطة بالسماد الدودي، دون وجود فروق معنوية عنـــد مســـتوى ثقـــة 95٪. بلغ وزن الشعير الطازج 124.7 جم / نبات، و 113.4 جم / نبات لنتيجة الحمأة والسماد الدودي مقارنة بـــ 82.8 جم / نبات للتربة بدون أي إضافات .بالنســـبة للبيقيـــة، كـــان الـــوزن الطـــازج 62

جرامًا/نباتًا للحمأة و57.6 جرامًا/نباتًا للسماد الدودي .ولوحظت زيادة مماثلة في معايير النبات الأخرى دون فروق معنوية .كما أظهرت المحاصيل المضافة إلى السماد الدودي والحمأة كفاءة اســتخدام الميــاه (WUE) مقارنة بتلك المزروعة بدون أي إضافات .زادت كفاءة استخدام المياه (كجــم/م3) مــن 13.9 إلى 20.96 للشعير مع الحمأة و19.05 للشعير مع السماد الدودي، ومن 7.05 إلى 15.18 للبيقية مــع الحمأة، و14.10 للبيقية مع السماد الدودي .تشير النتائج إلى أنه يمكن استخدام الديــدان الحمــراء فــي تحويل الحمأة المعالجة إلى سماد دودي، واستخدام السماد الدودي الناتج كسماد محســن للتربــة يعــزز الإنتاج.

الكلمات المفتاحية: ديدان الأرض، المغذيات النباتية، الحمأة، تعديلات التربة، خصوبة التربــة، ســماد دودي .