T.R.
ONDOKUZ MAYIS UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF SOIL SCIENCE AND PLANT NUTRITION

EFFECTS OF VERMICOMPOST ON MICROBIOLOGICAL PROPERTIES OF LETTUCE RHIZOSPHERE

Master's Thesis

Muhammad Danish TOOR

Supervisor
Prof. Dr. Rıdvan KIZILKAYA

II. Supervisor
Assoc. Prof. Dr. Lyubka Koleva VALKOVA

SAMSUN
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ACCEPTANCE AND APPROVAL OF THE THESIS

The study entitled **"EFFECTS OF VERMICOMPOST ON MICROBIOLOGICAL PROPERTIES OF LETTUCE RHIZOSPHERE"** prepared by **Muhammad Danish TOOR**, and supervised by **Prof. Dr. Rıdvan KIZILKAYA**, and **Assoc. Prof. Dr. Lyubka Koleva VALKOVA** was found successful and unanimously accepted by committee members as Master thesis, following the examination on the date 15.8.2023.

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Chairman	Prof. Dr. Rıdvan Kızılkaya Ondokuz Mayıs University Department of Soil Science and Plant Nutrition	☒ Accept ☐ Reject
Member	Assoc. Prof. Dr. Violina Angelova Agricultural University – Plovdiv Department of General Chemistry	☒ Accept ☐ Reject
Member	Prof. Dr. Coskun Gulser Ondokuz Mayıs University Department of Soil Science and Plant Nutrition	☒ Accept ☐ Reject

This thesis has been approved by the committee members that already stated above and determined by the Institute Executive Board.

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Prof. Dr. Ahmet TABAK
Head of Institute of Graduate Studies

DECLARATION OF COMPLIANCE WITH SCIENTIFIC ETHIC

I hereby declare and undertake that I complied with scientific ethics and academic rules in all stages of my Master's Thesis , that I have referred to each quotation that I use directly or indirectly in the study and that the works I have used consist of those shown in the sources, that it was written in accordance with the institute writing guide and that the situations stated in the article 3, section 9 of the Regulation for TÜBİTAK Research and Publication Ethics Board were not violated.

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15/08/2023
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Thesis Title : EFFECTS OF VERMICOMPOST ON MICROBIOLOGICAL PROPERTIES OF LETTUCE RHIZOSPHERE

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ÖZET

ARUL RİZOSFERİNİN MİKROBİYOLOJİK ÖZELLİKLERİ ÜZERİNE VERMİKOMPOSTUN TKİLERİ

Muhammad Danish TOOR
Ondokuz Mayıs Üniversitesi
Lisansüstü Eğitim Enstitüsü
Toprak Bilimi Ve Bitki Besleme Ana Bilim Dalı
Yüksek Lisans, Ağustos/2023
Danışman: Prof. Dr. Rıdvan KIZILKAYA
Danışman: Doç. Dr. Lyubka Koleva VALKOVA

Bu çalışmanın amacı, vermikompostun marul bitkisinin rizosfer bölgesindeki mikrobiyolojik özellikler üzerindeki etkilerini araştırmaktır. Deneme, Batavia marulu kullanılarak kontrollü çevresel koşullara sahip bir sera ortamında gerçekleştirilmiştir. Çalışmada, farklı vermikompost düzeyleriyle (V_O [0%], V_1 [1%], V_2 [2%] ve V_4 [4%]) muamele edilen rizosferdeki, toprak pH, elektriksel iletkenlik (EC), organik madde (OM), toprak solunumu (BSR), mikrobiyal biyomas karbon (MBC), dehidrogenaz aktivitesi (DHA), katalaz aktivitesi (CA), klorofil, bitki boyu, marul bitkisinin taze ve kuru ağırlığındaki değişimler araştırılmıştır.

Elde edilen sonuçlara göre, vermikompostun toprak pH üzerinde önemli bir etkisi olduğunu ve bitki varlığından bağımsız olarak yüksek uygulama dozlarının EC'yi artırdığı belirlenmiştir. Toprakta bitki köklerinin varlığı, yüksek vermikompost uygulama dozlarında hacim yoğunluğunu azaltırken organik madde içeriğini azaltıcı etkiye sahiptir. Bununla birlikte, çok düşük ve çok yüksek uygulama dozları, ortamdaki bitki bitki köklerinin varlığı ile mikrobiyal aktivite arasında karmaşık bir ilişki olduğunu gösteren MBC'de artışa neden olmaktadır. CA'nın ise vermikompost ilavesiyle tutarlı bir artış göstermediği belirlenmiştir. Öte yandan, vermikompost uygulaması, dehidrogenaz aktivitesini olumlu yönde etkilemiş ve böylece toprak mikrobiyal aktivitesini artırmıştır. Klorofil içeriğinin analizi, V_1'in klorofil a, b ve toplam klorofil seviyelerinde en yüksek değerlere sahip olduğunu, V_2'nin ise en yüksek karotenoid içeriğine sahip olduğunu ortaya koymuştur. V_1 ve V_2 ile muamele edilen bitkiler biraz daha yüksek ortalama boy gösterirken, V_2 ve V_4 uygulama dozlarında en yüksek taze bitki ağırlığı belirlenmiştir. Ayrıca, tüm vermikompost dozları (V_1, V_2 ve V_4), kontrol muamelesine (V_0) göre daha yüksek bitki kuru ağırlıklarına elde edilmiştir.

Genel olarak, bulgular vermikompostun toprak özelliklerini iyileştirmek ve tarım alanlarında bitki büyümesini artırmak için etkili bir organik gübre olarak kullanılabileceğini göstermektedir. Sonuçlar, genel bitki büyümesi için %1 ila %2 arasında değişen vermikompost dozlarının optimal olduğunu göstermektedir. Bu sonuçlar, vermikompostun rizosfer üzerindeki faydalı etkilerini anlama çabalarımıza katkıda bulunmakta ve tarımsal sistemlerde sürdürülebilir bir toprak yönetimi uygulaması olarak kullanımını desteklemektedir.

Anahtar Sözcükler: Vermikompost, Marul Rizosferi, Organik Uygulama, Mikrobiyal biyomas, Toprak Özellikleri, Sürdürülebilir Tarım

ABSTRACT

EFFECTS OF VERMICOMPOST ON MICROBIOLOGICAL PROPERTIES OF LETTUCE RHIZOSPHERE

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This study aimed to investigate the effects of vermicompost on the microbiological properties of lettuce rhizosphere. The experiment was conducted in a greenhouse with controlled environmental conditions using Batavia lettuce as the indicator plant. The study evaluated the changes in pH, electrical conductivity (EC), organic matter (OM), soil basal respiration (BSR), microbial biomass carbon (MBC), dehydrogenase activity (DHA), catalase activity (CA), chlorophyll, plant height, fresh and dry weight of lettuce plant in the rhizosphere treated with different vermicompost levels (V_O [0%], V_1 [1%], V_2 [2%], and V_4 [4%]).

The results indicated that vermicompost had a significant impact on soil pH, with higher treatment percentages leading to increased EC regardless of plant presence. The presence of plant roots in the soil had a reducing effect on bulk density at higher vermicompost treatment percentages, while decreasing organic matter content. However, both lower and higher treatment percentages resulted in increased MBC, suggesting a complex relationship between plant presence and microbial activity. CA did not show a consistent increase with vermicompost addition. On the other hand, vermicompost treatment positively influenced dehydrogenase activity, indicating an enhancement in soil microbial activity. The analysis of chlorophyll content revealed that V_1 had the highest levels of chlorophyll a, b, and total chlorophyll, while V_2 had the highest carotenoid content. Plants treated with V_1 and V_2 exhibited slightly higher average height, and those treated with V_2 and V_4 showed the highest fresh weight. Additionally, all vermicompost doses (V_1, V_2, and V_4) resulted in higher dry weights compared to the control treatment (V_0).

Overall, the findings suggest that vermicompost can be effectively used as an organic amendment to improve soil properties and enhance plant growth in agricultural fields. The data indicates that vermicompost doses ranging from 1% to 2% are optimal for overall plant growth. These results contribute to our understanding of the beneficial effects of vermicompost on the rhizosphere and support its application as a sustainable soil management practice in agricultural systems.

Keywords: Vermicompost, Lettuce rhizosphere, Organic amendment, Microbial biomass, Soil properties, Sustainable agriculture.

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Muhammad Danish TOOR

CONTENTS

SYMBOLS AND ABBREVIATIONS

g	: gram
mg	: milligram
cm	: Centimeter
P0	: With plants
P1	: Without plants
pH	: Potential of Hydrogen
EC	: Electrical Conductivity
OM	: Organic Matter
BSR	: Basal Respiration Rate
MBC	: Microbial Biomass Carbon
CA	: Catalase Activity
Kg/da	: Kilogram/decar
mg/L	: miligrams/liter
FAO	: Food and Agriculture Organization
FW	: Fresh Weight

FIGURES LEGENDS

TABLES LEGENDS

1. INTRODUCTION

Scientists in the twenty-first century face challenges from a rapidly increasing global population as well as insufficient food production, despite a decline in both the quantity and the quality of agricultural land, soil profile, quality of water and resources, global climate change, and changing weather patterns associated with climate change, which has led to a significant increase in the use of sustainable agriculture practices. Sustainable agriculture is a set of practices that protect the environment and natural resources while also meeting human needs. For a transition to sustainable food production, improved circular nutritional management is required. Vermicompost appears to be a soil conditioner as well as plant food produced by earthworm species like the red worm (Eisenia foetida) by modifying the chemical and physical characteristics of organic organic material and animal waste (Demir et al., 2010).

Vermicompost contains many nutrients such as NO3, PO4, Ca, K, Mg, S, and micronutrients that have similar effects on plant development and yield as synthetic fertilizers applied to the soil (Singh et al., 2008). In the same way, vermicompost has a high proportion of humic substances (humic acids, fulvic ac ids, and humin), supplying many sites for chemical reaction; microbial components recognized to improve plant growth as well as disease suppression via the activities of bacteria (Bacillus), yeasts (Sporobolomyces and Cryptococcus), along with fungi (Trichoderma), plus chemical antagonists such as phenols as well as amino acids (Nagavalemma et al., 2004).

It has also been promoted as a beneficial soil amendment for applications such as integrated field crop management practices. According to an organic farming pioneer (Shroff and Devesthali, 1994), vermicompost is a biofertilizer as well as an alternative to chemical fertilizers. Vermicompost would improve soil and crop production in a sustainable manner by improving soil organic carbon condition, soil flocculation, soil water holding capacity, and nutrient availability (Rajkhowa et al., 2000). Vermicompost, according to Vasanthi and Kumaraswamy (1996), contributes to an increase in soil solubilized nutrients. Because it transports nutrients along with stabilized, fine, peat-like organic fertilizers with a low C: N ratio, vermicompost is beneficial for maintaining adequate productivity and soil fertility (Przemieniecki, 2021). It also has increased microbial activity, which revitalizes soils, as well as

increased porosity, microbial activity, and moisture-holding capacity (Domnguez, 2004). Vermicompost is regarded as an effective soil amendment because it contains exchangeable phosphate, nitrates, soluble potassium, calcium, and magnesium, as well as growth hormones and beneficial enzymes (Bejbaruah, 2013).

In recent years, changes in eating and lifestyle habits have increased demand for fresh vegetables, reflecting a consumer's desire for better, healthier, and more appetizing foods. Lettuce (Lactuca sativa L.), a member of the Asteraceae family, is regarded as one of the most important high-value vegetables in the Philippines. It can be either a leaf or a head salad vegetable that is widely grown in temperate regions and some favored locations, particularly at higher elevations. It is a staple in Filipino diets due to its high vitamin content, particularly vitamin C. Lettuce is the most popular vegetable salad in the world, containing anticancer phytochemicals as well as vitamins A, antioxidants, folic acid, minerals, and sugars (Kim et al., 2016a). Lettuce also contains a lot of fiber, carbohydrates, protein, and fat. Increasing lettuce production in response to increased demand usually necessitates the purchase of more land. Because alluvial sandy soils (Tropepts suborder) account for 46.7% of all soil types in the Philippines (BSWM), sandy soils can be a good place to start growing lettuce. In the domestic market, lettuce has emerged as a major cash plant. Organic manure alternatives help to eliminate or reduce the careless use of chemical fertilizers, which harms the ecological balance and raises production costs. Organic farming could play an important role in reducing the levels of toxic compounds (e.g. nitrates) in lettuce crops, improving leaf quality and maximizing profits and yields (Kim et al., 2016b).

Vermicomposting is a low-cost, environmentally friendly method of treating organic matter that results in vermicompost by developing biodegradation and medium-temperature consistency through the interaction of microbes and earthworms. Vermicompost improved the growth and yield of a variety of field crops, including vegetables, flowers, and fruit crops. Arancon et al. (2003) reported an increase in tomato, lettuce, and pepper growth rates in response to 8%-10% vermicompost substitutions into peat mixtures. Jahan et al. (2014) investigated the effects of different vermicompost doses on cauliflower plants (0, 1.5, 3, and 6 ton/ha). The field supplemented with 6 tons/ha of vermicompost yielded the highest yield, according to the results.

When vermicompost was applied, however, the lettuce plant's height and root size decreased when compared to the control group. According to Bai and Malakout (2007), increasing vermicompost doses increased N, K, and P uptake in some vegetables. Atiyeh et al. (2000) discovered that pig manure Vermicompost (VC) had a significant effect on the growth and yield of greenhouse tomatoes. When compared to horse compost, chicken compost, and chemical fertilizer, the use of VC increases yield and vitamin C while using only 60-70% of the field capacity (Yang et al., 2015). Arancon et al. (2005) investigated the impact of VC derived from food waste and paper waste on pepper yield and growth. They discovered that VC application significantly increased marketable fruit weights and plant shoot biomass while decreasing non-marketable pepper fruit yields. Furthermore, VC increased pineapple yield and fruit weight, as well as average plant length, width, and number of leaves (Chaudhuri et al., 2016). Vermicomposting and composting for 25 weeks with dairy cattle manure added at a rate of 18.5 t ha-1 was found to be sufficient for achieving optimal Ca, K, Mg, and Mn leaf nutrient concentrations in lettuce var. Great Lakes (Hernández et al., 2010). Vermicomposting is one of the primary methods for recycling vegetable and animal organic waste to create an organic fertilizer rich in the elements required for plant growth (Amira et al.,2021).

Excessive synthetic fertilization pollutes soil (Zand-Parsa and Sepaskhah, 2006), and toxic components for human health accumulate in vegetables (Ruiz et al., 1999). Nonetheless, nitrate is toxic if it exceeds 5 mg per kg of human body weight, according to FAO/WHO (1999). As a result, nitrogen fertilization management in vegetable farming must be planned carefully. Vermicompost applications may be expanded in the coming years, according to scientists working on a solution to this problem. Because vermicomposting and agricultural residue materials contain nutrients, they can help to restore soil and water degeneration caused by inorganic fertilizers.

This study aims to investigate the effects of various vermicompost doses on the rhizospheric microbial characteristics of lettuce. The goal of the study is to identify any changes in the nutrient element content and agronomic characteristics of the lettuce by analyzing the effects of vermicompost application. It also seeks to clarify how applying vermicompost affects the rhizosphere of lettuce's microbiological characteristics. This study will provide important knowledge about the potential advantages and effects of vermicompost doses on lettuce plants.

2. LITERATURE REVIEW

2.1. History of Vermicompost

Since the time of Charles Darwin, scientists have acknowledged the significance of earthworms in enhancing soil fertility. Earthworms serve as natural bio-reactors that accelerate the decomposition of organic waste by improving aeration and increasing the surface area of the substrate (Dominguez et al., 1997). Within the decomposition system, earthworms fulfill multiple roles, including mixing, aerating, crushing, chemically degrading, and biologically stimulating the organic matter (Edwards, 1995). Vermicompost, in collaboration with microorganisms, plays a crucial part in breaking down organic waste and sustaining the nutritional flow within the system. The use of earthworms for decomposing organic waste gained momentum in the early 1980s. As plant residues and dung from rural and urban areas pass through the digestive tract of worms, they undergo fragmentation and mixing. The resulting excreta, known as vermicompost, possesses the ability to enhance soil health and nutrient levels. Vermiculture refers to the process of converting biodegradable waste, such as farm waste, market waste, kitchen waste, bio-wastes from agro-based industries, and livestock waste, into nutrient-rich vermicompost as it passes through the digestive system of worms. Vermi worms are employed as biological agents in vermicomposting to consume waste materials and subsequently deposit their excreta.

Vermicomposting is a biotechnological process that involves the use of specific earthworm species to enhance waste decomposition and produce high-quality compost. Unlike traditional composting methods, vermicomposting exhibits distinct characteristics (Gandhi et al., 1997). It operates under mesophilic conditions, utilizing microorganisms and earthworms that thrive within a temperature range of 10 to 32 degrees Celsius (not the ambient temperature, but the temperature within the moist organic material pile). Notably, the earthworm gut plays a crucial role in a poorly understood transformation process that leads to the formation of earthworm castings, also known as worm manure. These castings are enriched with beneficial microorganisms, plant growth regulators, and possess pest repellent properties. In essence, earthworms possess the remarkable ability to convert waste materials into a valuable resource through their biological alchemy (Vermi Co, 2001).

2.2. Production Methods of Vermicompost

To produce vermicompost, begin by layering coconut shell, tiles, or polythene sheeting over a cement ring. Cover the sheet with a 15-20 cm thick layer of organic waste, sprinkling rock phosphate on it if cow dung slurry is available. The layers should completely encircle the ring, and the top should be covered with dirt or cow dung. Allow 15 to 20 days for the material to start decomposing and the heat to dissipate. Once the heat subsides, introduce 500 to 700 free-selected earthworms, making sure they emerge through the cracks. To protect the earthworms from birds, cover the ring with a mesh or gunny bag. Keep the earthworms' bodies moist and warm by sprinkling water every 3 seconds. Depending on the substrate used, such as organic waste or sericulture waste, vermicompost is typically ready in about 2 months or 4 weeks, respectively. The final vermicompost is black in color, light in weight, and odourless. After drying for a few days, separate the earthworms from the compost by filtering the lower portion. The compost should be stored in bags in a cool place. When extracting the compost, create a new pile and repeat the process. These instructions are based on the study conducted by Nagavallemma et al. in 2004.

2.3. Overview of Lettuce

Lettuce (Lactuca sativa L.) belongs to the Asteraceae (Compositae) plant family, which is globally distributed and considered to be the largest plant family, comprising an estimated 23,000 to 30,000 species. The classification of Lactuca species within the subfamily Cichorioideae, tribe Cichorieae (Lactuceae) based on morphometric characteristics has been a subject of controversy in the past. However, recent molecular analyses have supported this classification, providing clarity on the tribal affiliations (Funk et al., 2005).

Lettuce holds significant economic value, ranking as one of the second-most valuable vegetable in the world. China is the largest producer of lettuce globally, accounting for nearly half of the world's output, which exceeded 11 million metric tons, more than double the production of the United States. Since 1980, global lettuce production has witnessed a 2.7-fold increase, reaching 22.4 million metric tons in 2005 (FAO 2006). This growth in production was primarily driven by an expansion in planted acreage rather than an increase in yield. From 1980 to 2005, lettuce yield (in hectograms per hectare) increased by 118%, while maize, potato, paddy rice, and tomato yields experienced increases of 149%, 135%, 146%, and 128%, respectively

(FAO 2006).

2.4. Application on vermicompost on vegetable crops

Production studies on tomatoes (Lycopersicum esculentum), eggplant (Solanum melongena), and okra (Abelmoschus esculentus) have shown promising results (Atiyeh et al., 1999). In another investigation, the effects of earthworms, vermicompost, cow dung compost, and chemical fertilizers on okra growth (Abelmoschus esculentus) were examined. The presence of worms and vermicompost significantly enhanced flower and fruit production in the vegetable crop. Notably, plants treated with worms and vermicompost exhibited a significantly lower occurrence of diseases such as "Yellow Vein Mosaic," "Color Rot," and "Powdery Mildew" (Agarwal et al., 2010).

In India, a study evaluated the yield of potatoes (Solanum tuberosum) using vermicompost in reclaimed sodic soil. The application of vermicompost at 6 tons/ha resulted in significantly higher potato productivity (21.41 tons/ha) compared to the control group (4.36 tons/ha). Additionally, vermicompost application led to reduced soil sodicity and increased nitrogen (N) content (Ansari, 2008). Comparative research on organic waste, including earthworm vermicast, and chemical fertilizers investigated their effects on the growth of garden peas (Pisum sativum). Vermicast demonstrated superior performance, promoting more green pod plants, higher green grain weight per plant, a greater percentage of protein concentration and carbohydrates, and increased green pod yield (24.8% - 91%) compared to chemical fertilizer (Meena et al., 2007).

A study on potato (Solanum tuber) production revealed that the use of vermicompost, either alone or in combination with chemicals, positively influenced various growth and yield parameters. These included total chlorophyll content and leaf structure, dry matter, flower appearance, fruit production, fruit length, fruits per plant, dry weight of 100 seeds, yield per plot, and yield per hectare. Plots treated with 2.5 tons/ha of vermicompost demonstrated the highest fruit yield, reaching 109 tons/ha (Karmegam and Daniel, 2008). Furthermore, vermicompost has been found to enhance the nutritional quality of several vegetable crops, including tomatoes (Gutiérrez-Miceli et al., 2007), Chinese cabbage (Wang et al., 2010), spinach (Peyvast et al., 2008), and strawberries (Singh et al., 2008).

2.5. Effect of Vermicompost on Plant Growth and Yield attributes of Crop

Kumar and Gupta (2018) conducted a study to examine the impact of vermicompost and chemical fertilizers on radish growth and yield. The results of their experiment revealed that vermicompost exhibited superior fertilization properties compared to other fertilizers due to its nutrient availability and contribution to the sustainability of agriculture. The sustainability of agriculture holds significant importance in ensuring food security for the population of a country. Notably, in the vermicompost plot, plant heights reached 50cm, while in the cow dung, urea, and control treatments, the heights were 41cm, 39cm, and 17cm, respectively. The tubers weighed 152gm, 133gm, 120gm, and 49gm in the vermicompost, cow dung, urea, and control treatments, respectively. Additionally, the number of fruits per plant was recorded as 44, 36, 25, and 15 in the vermicompost, cow dung, urea, and control treatments, respectively. Stem diameters followed a similar trend, with measurements of 1.40cm, 1.16cm, 0.96cm, and 0.76cm in the vermicompost, cow dung, urea, and control treatments, respectively. The dry matter yield was found to be 41.36gm, 39.92gm, 35.25gm, and 21.50gm in the vermicompost, cow dung, urea, and control treatments, respectively.

In another study, Durak et al. (2017) explored the effects of vermicompost on lettuce yield and various growth parameters. The experiment involved the application of vermicompost at rates of 100, 200, and 300 kg per decare, alongside conventional fertilization. The findings demonstrated that the application of vermicompost at a rate of 300 kg/da resulted in improved yield and growth parameters compared to the control and conventional fertilization methods.

2.6. Physico-Chemical Changes in Soil after Vermicompost Application

Tharmaraj et al. (2011) conducted a study to investigate the impact of vermicompost on soil physical and chemical properties during samba rice cultivation. The researchers performed soil sampling and plant growth measurements at both early and late stages of a two-month period. The study focused on the effects of various vermiproducts, including vermicompost, vermiwash, and a mixture of vermicompost and vermiwash, on soil physicochemical properties. The results of the study showed that the application of vermicompost significantly improved several soil properties compared to the control soil. These improvements included increased electrical conductivity (EC), enhanced pH reduction, improved porosity, moisture content, water

holding capacity, as well as increased levels of nitrogen, phosphorous, calcium, magnesium, and potassium. In contrast, the control soil exhibited minimal physicochemical values.

Furthermore, the addition of vermicompost led to improvements in the physical properties of the soil, such as increased water holding capacity, moisture content, and porosity. Plants treated with vermiproducts exhibited accelerated growth and higher yields compared to the control plants. Notably, the combination of vermicompost and vermiwash resulted in the greatest plant growth parameters, including the number of leaves, leaf length, plant height, and root length. The study findings demonstrated that vermicompost application had a significant positive impact on the soil's physical, chemical, and plant growth parameters. Vermicompost was found to enhance the physical, chemical, and biological properties of the soil. Previous research by Ansari (2007) also supported the beneficial effects of vermicompost on crop yield parameters in wheat, paddy, and sugarcane. Additionally, Hidlago et al. (2006) observed improved plant growth, leaf growth, and root length with the incorporation of earthworms.

The suitability of vermicompost-amended soil for sustaining plant growth and biological activity was determined based on the soil's physical and chemical properties, which rely on soil organic matter. Soil plays a crucial role in facilitating essential processes such as organic waste decomposition and detoxification of toxic compounds, supporting biological systems' major requirements.

2.7. Impact of Vermicompost on Soil Biological Properties

Uz and Tavali (2014) conducted a study in Turkey's semiarid Mediterranean region to assess the direct impact of vermicompost on specific soil biological properties in an alkaline soil with high lime. The researchers compared the changes observed after the addition of vermicompost with those observed after adding farmyard manure. The study involved incubating soil and organic fertilizer mixtures at various doses under greenhouse conditions. Soil samples were collected at regular intervals and subjected to analysis to measure biological parameters such as dehydrogenase, β-glucosidase, urease, alkaline phosphatase activities, and total aerobic mesophilic bacteria count.

The results showed that, overall, soil dehydrogenase activity appeared to be independent of the dosage of organic amendments. However, when considering

individual sampling periods, the addition of organic amendments, including vermicompost, led to an increase in dehydrogenase activity. The levels of β-glucosidase, urease, alkaline phosphatase activity, and aerobic mesophilic bacterial count fluctuated in the vermicompost treatments but remained significantly higher than in the control group. A slight but statistically significant difference in urease activity was observed between the different organic amendments. The study also revealed that vermicompost significantly increased the number of bacteria in the soil. These findings suggest that vermicompost has the potential to be used as a substitute for farmyard manure in alkaline calcareous soils, effectively enhancing and sustaining soil biological activity.

2.8. Researches related to vermicompost impact on vegetable crops

The effects of vermicompost on soil contaminants have been extensively studied by various researchers. Drinkwater et al. (1995) and Gopinath et al. (2008) observed that vermicompost-applied soils exhibited significantly higher pH levels compared to soils treated with farmyard manure (FYM) or mineral fertilizers. Alam et al. (2007) conducted a study in Bangladesh, focusing on the effects of vermicompost and NPK fertilizers on potato growth. They concluded that combining inorganic fertilizers with 5-10 t/ha of vermicompost resulted in higher potato production and economic profitability.

Rajkhowa et al. (2000) highlighted the long-term benefits of vermicompost on soil and crop production. Their research demonstrated that vermicompost improved soil organic carbon status, water holding capacity, soil flocculation, and nutrient availability. Sreenivas et al. (2000) investigated the impact of vermicompost and fertilizer application on nitrogen availability in soil and its uptake by ridge gourd plants. Their findings indicated that increasing the amount of vermicompost resulted in a significant increase in soil nitrogen availability and ridge gourd uptake, with the best results obtained with 50% of the recommended fertilizer rate combined with 10 t/ha of vermicompost.

Muhammad Ali et al. (2007) conducted a study on lettuce plants, comparing the effects of pure worm cast (vermicompost), green waste-derived compost, and different compost mixtures. They found that a 20/80 (v/v) compost blend resulted in optimal plant biomass production and chlorophyll content. Moreover, the 50/50 and 20/80

(v/v) compost mixtures exhibited the highest plant fresh and dry weights.

Madan and Rathore et al. (2015) investigated the impact of compost and vermicompost on chickpea plant growth. They discovered that 40% vermicompost concentration significantly improved various growth parameters, including root and shoot length, fresh and dry biomass, total chlorophyll, and carotenoids. Bevacqua and Mellano (1993) observed that compost-treated soils had lower pH levels and higher organic matter, primary nutrient, and soluble salt levels.

Bryan and Lance (1991) and Maynard (1993) independently found that compost-amended soils resulted in increased fruit production in tomatoes. Kolte et al. (1999) reported that adding vermicompost, along with 50% of the recommended inorganic fertilizers, increased tomato yields. Arancon et al. (2008) demonstrated that vermicompost stimulated plant flowering, leading to increased flower number, biomass, and yield. Additionally, vermicompost was shown to improve the nutritional quality of certain vegetable crops while enhancing overall plant productivity and growth.

However, Gopinath et al. (2008) found that vermicompost application during the transition period in organic farming reduced wheat grain yield by 28-41%. Similarly, Ramesh et al. (2005) reported a 12.6% reduction in wheat grain yield when compared to mineral fertilizers. Bhaskaran et al. (2009) observed a 56.14% increase in protein content, 8.5% decrease in fiber content, and improved keeping quality and palatability in cowpea treated with vermicompost.

Ramanjaneyulu et al. (2013) found that top dressing with vermicompost and basal application of farmyard manure (FYM) enhanced the growth of organically grown red gram, enabling the plants to withstand mid-season dry spells. The combined application of FYM (5 t/ha) and vermicompost (2.5 t/ha) resulted in an 18.4% higher mean red gram seed yield compared to conventional inorganic farming. Gangaiah et al. (2013) reported higher seed yields in inorganic production systems compared to organic systems, both with and without FYM/vermicompost during the conversion period. They also noted an increase in organic carbon content and available phosphorus in soil amended with FYM and vermicompost (Reddy et al., 1998).

Padmavathiamma et al. (2008) investigated the yield of pea plants when treated

with vermicompost (10 t/ha) and recommended doses of N, P, and K fertilizers. They found that the combined application resulted in significantly higher pea yield compared to separate fertilizer applications. Webster (2005) observed that vermicompost application led to increased 'cherry' yield in tomatoes for three years following a single application, especially when the vermicompost was covered with mulch. In vineyards, vermicompost-treated vines produced 18% more bunches and 23% more grapes.

Uma and Malathi (2009) compared the growth, yield, and quality parameters of Amaranthus sp. plants grown in vermicompost plots and chemical fertilizer plots, finding superior results in the vermicompost-treated plants. Suthar (2009) reported higher growth and yield parameters in garlic plants treated with vermicompost (20 t/ha) compared to chemical fertilizer-treated plants.

Singh et al. (2011) highlighted the presence of heavy metals in compost and the ability of earthworms to remove and accumulate them in vermicast. Dia et al. (2004) demonstrated that earthworms can remove excess metals and bioaccumulate them. Pattnaik and Reddy (2010) explained how earthworms convert the organic portion of hazardous waste into nutrients and reduce heavy metal content through their accumulation in the vermicomposting process.

Tognetti et al. (2005) conducted a comparison study between municipal waste-based compost and vermicompost. They found that vermicompost application resulted in higher ryegrass yield compared to compost, possibly due to higher nutrient levels, microbial size, and activity. Other studies have also reported increased growth and yield in plants such as green beans and Salvia officinalis when vermicompost was used instead of compost (El-Haddad et al., 2020).

The mechanisms underlying vermicompost's disease suppression effects are not yet fully understood. Noble and Coventry (2005) proposed that vermicompost could suppress pathogens either directly or by inducing a defense response in plants. Competition, antibiosis, and parasitism are potential mechanisms involved in pathogen suppression. Vermicompost can increase soil microbial biomass, alter the abundance and diversity of soil fauna, and promote a wider range of organisms acting as biocontrol agents (Gunadi et al., 2002). Recent evidence suggests that vermicompost

extracts used as foliar sprays effectively reduce the prevalence of fungal diseases, including Phytophthora infestans, Erysiphe pisi, and Erysiphe cichoracearum (Zaller, 2006; Singh et al., 2003).

3. MATERIAL AND METHODS

3.1. Soil

The experimental soil was collected from an agricultural field (Figure 3.1) at Ondokuz Mayis University in Samsun, Türkiye (41° 21' 49.9" N, 36° 11' 19.7" E). The site experiences a mean annual maximum temperature of 27.7°C, a minimum temperature of 5°C, and a relative humidity of 73%. The average annual precipitation in the region is 937.26 mm. Standard methods were employed to determine the soil's physical and chemical properties. The particle size distribution was determined using the hydrometer method (Bouyoucos, 1962). The CaCO3 content was measured using the volumetric method (Martin and Reeve, 1955), pH was determined using a 1:1 soil-water suspension and a pH meter (Rowell, 2014), and electrical conductivity (EC) was measured using a 1:1 soil-water suspension and an EC meter (Rowell, 2014). The Walkley-Black wet oxidation method with K2Cr2O7 was used to determine the total soil organic matter (SOM) and the determination of total nitrogen has been determined by the Kjeldahl method. (Rowell, 2014).

Figure 3.1. Field visit for the description of the soil sampling area

3.2. Vermicompost

The vermicompost used in the experiment was obtained from the Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Ondokuz Mayıs University. Standard methods were applied to conduct chemical analysis on the vermicompost. The chemical analysis of the organic wastes was conducted using standard methods: pH (1:1,w/v, waste-water suspension, pH-meter, Rowell, 2014), electrical conductivity (1:1, w/v, waste-water suspension, EC-meter, Rowell, 2014). Ash content

was determined by dry ashing (Miller et al., 1996), and organic matter content was estimated by dry ashing and calculating the organic carbon using a conversion factor of 1.724 (Rowell, 2014). Total phosphorus in organic wastes was determined by dry ashing method, and total nitrogen content was determined by the Kjeldahl method (Bremner, 1965).

3.3. Batavia lettuce

Batavia lettuce (Figure 3.2) was selected as the test and indicator plant for this experiment. Lettuce is a widely cultivated vegetable and frequently used as a model plant in scientific studies due to its sensitivity to environmental conditions and nutrient deficiencies. Its fast growth, relatively short life cycle, and observable physiological responses make it an appropriate choice for evaluating the effects of different treatments or conditions in plant experiments.

Figure 3.2. Description of the indicator plant used

3.4. Experimental Design

A Completely Randomized Design (CRD) was employed to arrange the experiment, incorporating two factors: Vermicompost doses (0%, 1%, 2%, and 4%) and Application type (With and without plants). A total of 24 pots were used in this experiment, with 12 pots containing plants and 12 pots without plants. To ensure accuracy and reliability, three replicates of each dose were established, including three pots used as controls for both with and without plants. This resulted in six pots for each treatment.

To prepare the soil for the experiment, approximately 500kg of soil was collected from an agricultural field and naturally dried in the shade for 15-20 days. Subsequently, the dried soil was crushed using a wooden hammer and manually sieved through a 4mm sieve to achieve a homogeneous soil condition for each treatment. Each pot was then filled with 3kg of this prepared soil. The different treatments were assigned as follows:

Without Plants:

P0V0: Control (without vermicompost addition)

P0V1: 1% vermicompost added

P0V2: 2% vermicompost added

P0V4: 4% vermicompost added

With Plants:

P1V0: Control (without vermicompost addition)

P1V1: 1% vermicompost added

P1V2: 2% vermicompost added

P1V4: 4% vermicompost added

The experiment was conducted under controlled environmental conditions to ensure reliable and consistent results. The temperature was carefully regulated throughout the experiment to minimize the potential impact of temperature fluctuations on the plants. Rainwater was used for irrigation to minimize the presence of contaminants from other water sources. Soil moisture content was closely monitored and maintained near field capacity, representing the maximum amount of water that the soil can hold. The pots were weighed every two days to assess moisture depletion and replenished accordingly to maintain optimal moisture levels for plant growth. This meticulous attention to detail ensured that the experiment was conducted under highly controlled conditions, minimizing the influence of external factors on the obtained results.

3.5. Overall growth of lettuce during experimental trails

Transplanting of the romaine lettuce was done on 29th Nov 2022. During the experimental trials, the overall growth of lettuce was observed at different stages, starting from transplanting to harvesting. The first stage was transplanting, which is the process of moving seedlings from the nursery bed to the main field. After one day of transplanting, the lettuce showed signs of acclimatization and started to adapt to the new environment. By the 5th day of transplanting, the lettuce had grown to a considerable size and showed healthy growth. By the 35th day of transplanting, the lettuce had reached maturity and was ready for harvesting. At the 50th day of

transplanting, the lettuce had fully grown and was at its maximum size, indicating optimal growth during the experimental period. Finally, the lettuce was harvested, and the quality and yield were analyzed, providing valuable insights into the effectiveness of the growth process (Figure 3.3).

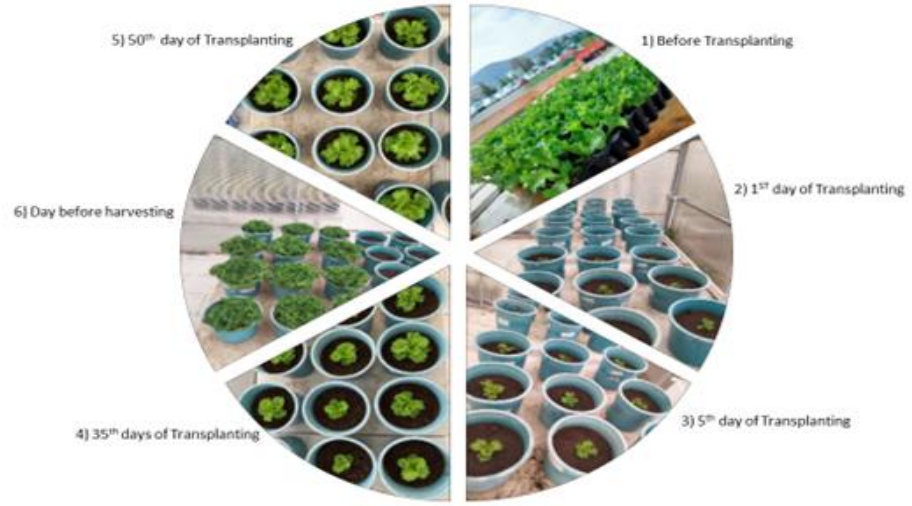

Figure 3.3. An overview of lettuce growth during experiment

3.6. Plant growth stage

Every day during the plant growth stage, different data were gathered to track each plant's development. The weight of the pot (g) was one of the parameters that was recorded. The field capacity of the soil was initially calculated to ensure proper irrigation. The pot's final weight served as a guide for daily irrigation, preventing either overwatering or underwatering of the plants.

Calculating evapotranspiration (ml) was another significant consideration. The amount of water evaporated by the plants from the pots over the course of the experiment was calculated. This was done by comparing the pot's initial weight before irrigation with its final weight after the allotted amount of time. These data points offered insightful information into the behavior and water needs of the plants, enabling proper irrigation management and ensuring the best possible growth conditions.

3.7. Maturation stage

On January 23, 2023, the lettuce plants were ready for harvest after 1 month and 25 days of growth. Before the harvest, a variety of agronomical factors were gathered

to ensure accuracy and collect thorough data. These variables included the centimeter-based plant height as well as the estimation of plant biomass. The weight of each pot containing the plants was measured before harvesting, and the weight after harvesting was subtracted, giving the difference in grams, which was used to calculate the plant biomass. Before moving on to the subsequent analysis, this meticulous approach made sure that the agronomic traits of the lettuce plants were accurately captured.

3.8. Laboratory Analysis

In order to assess the soil health and quality, soil samples were collected from each pot in two batches after the plants were harvested. The first batch of soil was collected immediately after harvesting and was carefully sealed in a plastic bag, then stored in a refrigerator. These soil samples were earmarked for soil biological analysis, as it was important to preserve the microbial activity present in the soil. On the other hand, the second batch of soil samples was collected and allowed to air-dry for 10 days. This batch of soil samples was used to conduct soil physiochemical analysis, which included evaluating the soil texture, pH levels, nutrient composition, and other related parameters.

3.8.1. Post-treatment soil biological analysis

The tests mentioned aim to evaluate different soil biological parameters. The first parameter is microbial carbon biomass, which can be measured using the method developed by Anderson and Domsch (1978). This test measures the amount of carbon present in the microbial cells in the soil. The second parameter is basal soil respiration, which can be evaluated using the method proposed by Anderson (1982). This test measures the rate at which carbon dioxide is released from the soil due to the microbial respiration process. The third parameter is dehydrogenase activity, which can be determined using the method developed by Pepper et al. (1995). This test measures the activity of enzymes that are produced by soil microorganisms and are involved in the process of organic matter decomposition. The fourth parameter is catalase activity, which can be assessed using the method developed by Beck (1971). This test measures the activity of enzymes that break down hydrogen peroxide into water and oxygen and indicates the ability of soil microorganisms to protect themselves from oxidative stress. Together, these tests provide valuable information about the activity and health of soil microorganisms, which is crucial for understanding the functioning of soil ecosystems and their role in supporting plant growth and nutrient cycling.

3.8.2. Post-treatment physiochemical analysis

A number of post-treatment physiochemical analyses were carried out during the experimental trial to assess the effects of various vermicompost doses on lettuce plants. A 1:1 (w/v) soil-to-water suspension was used to measure the pH and electrical conductivity (EC) levels using the water suspension method, as described by Bayraklı (1987). The 'Walkley-Black' chromic acid wet oxidation method, as described by Nelson and Sommers (1983), was used to measure the amount of soil organic matter (SOM). Based on the findings of this analysis, the amount of organic matter that is currently present in the soil was calculated. These analyses shed important light on the organic content and physiochemical characteristics of the soil, revealing potential effects of vermicompost doses on lettuce plants. After harvesting, a fresh leaf sample weighing 0.2 g was taken, and the contents of the four types of chlorophyll—chlorophyll a, chlorophyll b, and total chlorophyll—were determined in accordance with Witham et al. (1971). A 0.5g dried plant sample was weighed and dry ashed for 4 to 8 hours at 550°C in a furnace after the plant samples had been dried at 65°C with aeration to a constant weight. The iron content of the ash was assessed using an atomic absorption spectrophotometer after it had been dissolved in hydrochloric acid (HCl) (Jones et al., 1991).

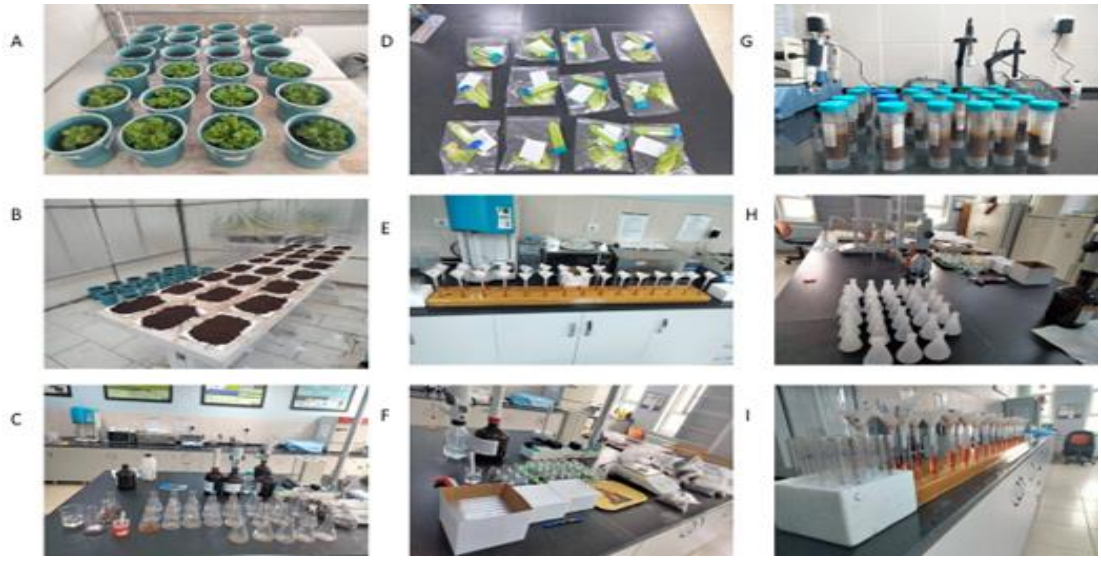

Figure 3.4. An overview of different biochemical and soil biological analysis

A = Experimental plants; B = Soil for lab analysis = Soil basal respiration rate (BSR) analysis; D = Chlorophyll analysis; E, I = Catalase analysis; F, H = Dehydrogenase analysis; G = pH and EC measurement

3.9. Lettuce Harvesting

On January 23rd, 2023, Batavia lettuce was harvested and underwent immediate post-harvest handling. To ensure accurate measurements, the fresh weight of each lettuce was measured using a digital weighing scale sensitive to 0.01g. Special attention was given to remove any soil or other particles from the lettuce, to obtain an accurate weight measurement.

Figure 3.5. Harvesting of Batavia lettuce

3.10. Dry mass of lettuce (g)

In order to calculate the dry mass of lettuce, freshly harvested lettuce after weighting was placed in an oven at 105˚C for 2 days until it reached constant weight to determine dry weight. The dry matter content was then calculated from the fresh and dry lettuce mass in grams. The formula for calculating the dry matter is as follows.

$$\textbf{Dry matter content (g)} = \frac{\textbf{Dry mass (g)}}{\textbf{Fresh mass (g)}} \times \textbf{100}$$

3.11. Statistical Analysis

Using the JMP program, the experiment's results were statistically assessed. JMP is a collection of software tools for statistical analysis created by JMP, an SAS Institute subsidiary, using a totally random design. The Duncan test was used to compare the means of the results at the 0.01 and 0.05 level, and the F values for significant applications were provided with ** at the 0.01 level and * at the 0.05 level.

4. RESULTS AND DISCUSSION

The results of some physical and chemical analyses of the soil sample used in the experiment are given in Table 4.1. The soil analysis results reveal important characteristics of the soil sample used in the experiment. The slightly acidic pH indicates that the soil has a pH value below 7, which can influence nutrient availability for plants. The non-saline nature, indicated by the moderate electrical conductivity (EC), suggests that the soil does not have excessive salt content, which is beneficial for plant growth. The moderate organic matter content indicates a moderate level of organic material present in the soil, contributing to its fertility and nutrient-holding capacity. The low lime content implies that the soil does not have a high concentration of calcium carbonate ($CaCO_3$), which can affect soil pH and nutrient availability. Additionally, the clay soil texture indicates good water-holding capacity and nutrient retention. Overall, these soil properties provide insights into its potential for supporting plant growth and may require specific nutrient management practices to optimize crop production.

Table 4.1. Physio-chemical analysis for pre-treated soil

Soil Properties	Results
pH	6.89
EC, µs/cm	552.67
Texture class	Clay
Silt, %	21.68
Sand, %	29.91
Clay, %	48.41
Soil Organic Matter, %	2.176
Total N, %	0.013
Lime ($CaCO_3$) content, %	1.79
C/N	9.92

The results of chemical analyses of the vermicompost used in the experiment are given in Table 4.2. The vermicompost analysis results demonstrate that the vermicompost has an alkaline pH and a relatively high concentration of soluble salts. However, it exhibits an impressive organic matter content, making it a valuable source of nutrients and organic material for soil improvement. The high total nitrogen content and optimal C/N ratio further enhance its value as an organic fertilizer. When used

appropriately, this vermicompost can contribute to enhancing soil fertility, improving plant growth, and promoting sustainable agricultural practices.

Table 4.2. Chemical analysis of vermicompost before application

	pH	EC, $\mu S\ cm^{-1}$	OM, %	OC, %	Ash, %	P, $mg\ kg^{-1}$	N, %	C/N
Vermicompost	9.11	5662	59.25	34.37	40.75	5361	2.17	15.84

4.1. Chlorophyll a

The results depict the influence of different doses of vermicompost on the growth of lettuce plants, specifically in terms of chlorophyll a content (Figure 4.1). Chlorophyll a serves as an indicator of plant growth and photosynthetic activity. Analysis of the data reveals that lettuce plants treated with V1 (1% vermicompost) exhibited the highest chlorophyll a content 0.76 mg g^{-1}, followed by the control treatment (0.71 mg g^{-1}). On the other hand, the lowest chlorophyll content (0.62 mg g^{-1}) was recorded in lettuce plants treated with V4 (4% vermicompost). Karademir and Kibar (2022) reported that vermicompost applications significantly increased the chlorophyll content of lettuce plants compared to the control treatment. The application of V1 led to a 22.30% increase in chlorophyll content compared to the control. Similarly, Kiran (2019) observed higher chlorophyll a, chlorophyll b, and total chlorophyll contents in vermicompost-treated lettuce plants compared to the control. Jabeen et al. (2018) also supported these findings, indicating that vermicompost application enhanced lettuce growth and chlorophyll a content. The study suggests that vermicomposting improved soil health and nutrient availability, thus promoting lettuce growth. These outcomes align with the findings of Pascual et al. (2019), who reported that vermicompost application increased soil fertility, resulting in better lettuce growth and higher chlorophyll a content. However, Ramesh et al. (2016) found no impact of vermicompost on lettuce growth or chlorophyll a content. The authors attributed this discrepancy to the quality of the vermicompost used or specific growing conditions. Additionally, Loffredo et al. (2017) emphasized that the concentration of vermicompost applied had a significant influence on lettuce growth and chlorophyll a content. Lower concentrations of vermicompost promoted lettuce growth, while higher concentrations had an adverse effect, possibly due to elevated salt content.

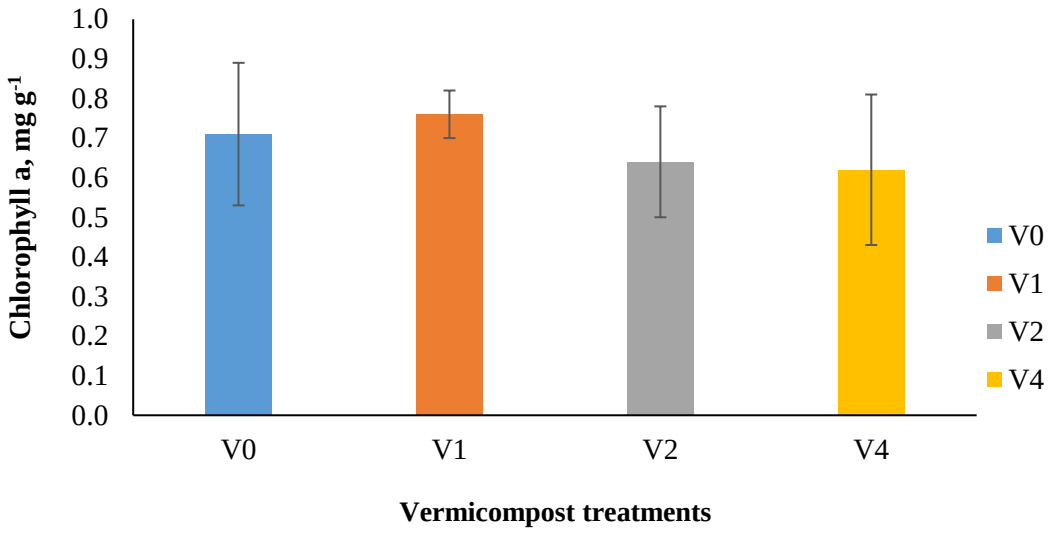

Figure 4.1. Effects of different vermicompost application doses on lettuce Chlorophyll a content

4.2. Chlorophyll b

The results presented in Figure 4.2 illustrate the impact of different doses of vermicompost (V0, V1, V2, V4) on the concentration of chlorophyll b in lettuce plants. Chlorophyll b is a crucial pigment involved in photosynthesis, reflecting the plant's ability to harness sunlight and produce energy. The data indicates that the highest concentration of chlorophyll b was observed in lettuce plants treated with V1 (1% vermicompost) at 0.4 mg g^{-1}, while the lowest concentration was recorded in plants treated with V4 (4% vermicompost) at 0.12 mg g^{-1}. Studies by Atiyeh et al.(2002) support these findings, indicating that vermicompost application significantly enhances lettuce growth, shoot and root dry weight, and chlorophyll b content. This may be attributed to the rich nutrient composition and beneficial microorganisms present in vermicompost. Yadav et al. (2015) similarly reported increased lettuce yield, growth, and chlorophyll b content with vermicompost application. The researchers suggested that the availability of essential nutrients such as nitrogen, phosphorus, and potassium, along with beneficial microorganisms present in vermicompost, contributed to improved growth and chlorophyll b content. Singh et al (2011) investigated the effects of vermicompost and chemical fertilizers on lettuce growth and chlorophyll b content in a separate study. They found that vermicompost, with its slow-release of nutrients, provided a reliable source of nourishment for lettuce plants, resulting in significantly higher growth and chlorophyll b content compared to chemical fertilizers. Furthermore, Huang et al. (2017) explored various ratios of

vermicompost and chemical fertilizers on lettuce growth and chlorophyll b content. They determined that a 50:50 mixture of vermicompost and chemical fertilizers produced the highest levels of lettuce growth and chlorophyll b. The researchers proposed that vermicompost, through its organic matter content and microorganisms, enhanced soil structure and nutrient availability, ultimately promoting lettuce growth and chlorophyll b content. These findings collectively support the notion that vermicompost application positively influences lettuce growth and chlorophyll b content, attributed to its nutrient-rich composition, beneficial microorganisms, and gradual nutrient release.

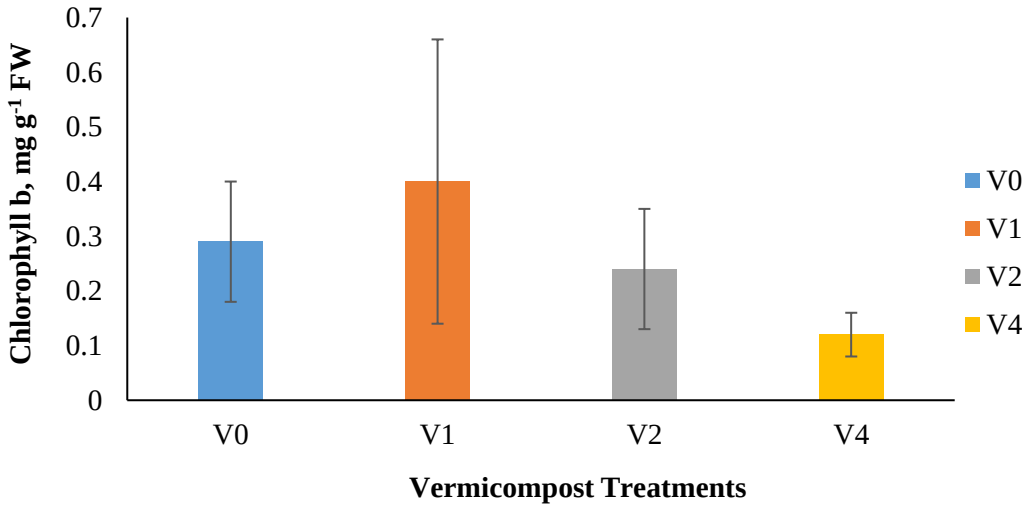

Figure 4.2. Effects of different vermicompost application doses on lettuce Chlorophyll b content

4.3. Total chlorophyll

The data presented in Figure 4.3 illustrates the impact of different doses of vermicompost (V0, V1, V2, V4) on the total chlorophyll content of plants. Total chlorophyll serves as an indicator of a plant's photosynthetic capacity and overall health. The results indicate that the highest dose of vermicompost (V1) had the most significant effect on the total chlorophyll content. Conversely, the lower doses (V0, V2, and V4) exhibited lower average total chlorophyll content, with V4 recording the lowest average of 0.74 mg g^{-1}. Numerous studies have demonstrated the positive effects of vermicompost application on plant growth and chlorophyll content. Khalid et al. (2017) reported a significant improvement in lettuce growth and chlorophyll content with the addition of vermicompost. Similarly, Gutiérrez-Miceli et al. (2008) observed enhanced lettuce growth and increased chlorophyll content following

vermicompost application. These positive effects can be attributed to various factors. One crucial component is the nutrient content of vermicompost. Vermicompost is rich in both macro and micronutrients, which are essential for plant growth and development (Hussain et al., 2017). Moreover, these nutrients are readily available to plants in forms that they can easily absorb (Gutiérrez-Miceli et al., 2008). Another contributing factor is the presence of beneficial microorganisms in vermicompost. Bacteria, fungi, and actinomycetes present in vermicompost can enhance soil structure, increase nutrient availability, and protect plants from pathogens (Atiyeh et al., 2002). Furthermore, vermicomposting improves soil fertility and health, thereby promoting plant growth and chlorophyll levels. According to Khalid et al. (2017), vermicompost enhances soil structure, increases organic matter content, and improves water-holding capacity. Taken together, the findings suggest that vermicompost application positively influences plant growth and chlorophyll content through its nutrient content, the presence of beneficial microorganisms, and the enhancement of soil fertility and health.

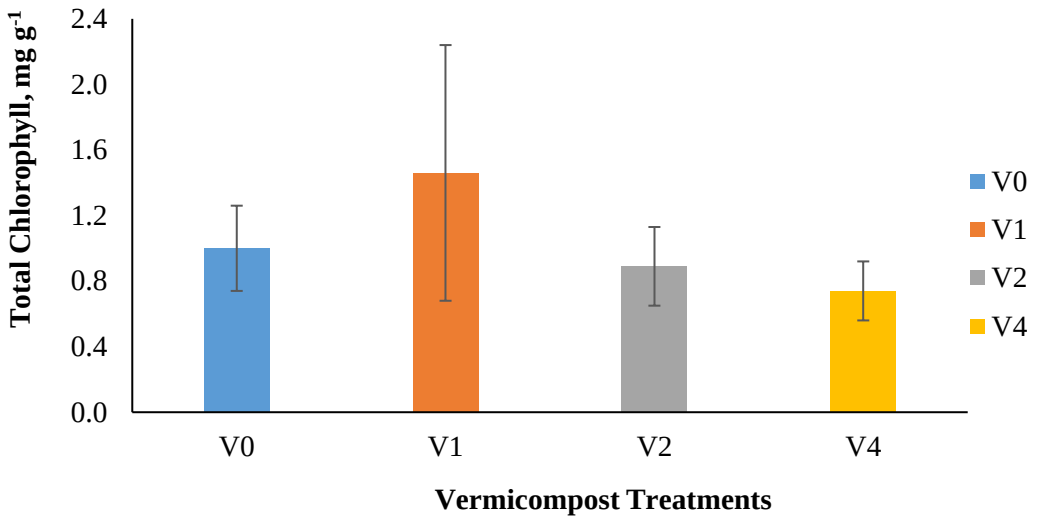

Figure 4.3. Effects of different vermicompost application doses on lettuce Total Chlorophyll content

4.4. Plant height

The results presented in Figure 4.4 indicate the effect of different doses of vermicompost (V0, V1, V2, V4) on plant height. It was observed that plants treated with V1 and V2 exhibited slightly higher average heights compared to the control group (V0), while plants treated with V4 showed slightly lower average heights. Durak et al. (2018) conducted a study demonstrating that vermicompost application

significantly increased yield and growth parameters compared to control and conventional fertilization methods. They also found a positive correlation between increasing vermicompost applications and an increase in leaf height for each plant. Their study revealed that applying vermicompost led to increased height of lettuce leaves and significantly higher fresh lettuce weights compared to the control group. These effects can be attributed to the improved availability of nutrients such as nitrogen, phosphorus, and potassium, which are essential for plant growth. Overall, the findings suggest that vermicompost application has a positive influence on plant height, with higher doses of vermicompost leading to increased growth parameters in lettuce plants.

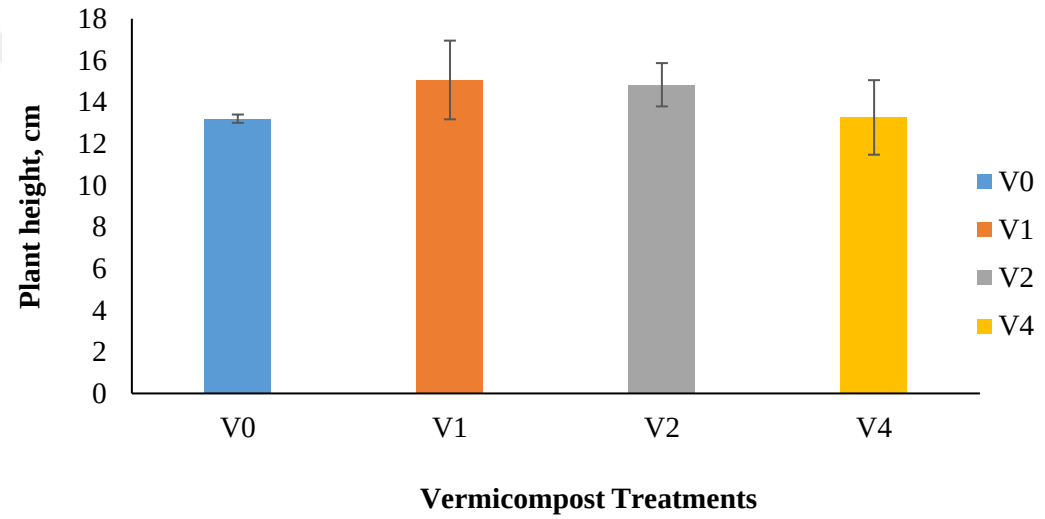

Figure 4.4. Effects of different vermicompost application doses on lettuce Plant Height

4.5. Plant fresh weight

The results presented in Figure 4.5 demonstrate the impact of different doses of vermicompost (V0, V1, V2, V4) on plant fresh weight. It is evident that plants treated with V2 vermicompost exhibited the highest fresh weight, closely followed by those treated with V4. Moreover, plants treated with V1 showed a significantly higher fresh weight compared to the control group (V0), indicating the positive effect of vermicompost on plant growth. These findings are consistent with the results reported by Adilolu et al. (2018), who observed that vermicompost applications significantly increased plant fresh weight compared to the control. Similar studies have also investigated the impact of vermicompost on lettuce growth and fresh weight. Naeem et al. (2017) found that vermicompost application significantly increased lettuce

growth, yield, and fresh weight. The study reported an increase in the nitrogen, phosphorus, and potassium contents of lettuce plants, indicating improved nutrient uptake. Suthar (2009) conducted research on vermicompost application and its effects on soil fertility, nutrient uptake, and lettuce growth. Their findings showed that vermicomposting significantly increased lettuce fresh weight, plant height, and root length. The study also highlighted the enhancement of soil microbial activity, which may have contributed to improved lettuce growth. Similar results were reported by Atiyeh et al. (2002), demonstrating that adding vermicompost significantly increased lettuce yield and growth. The study found that vermicompost application resulted in higher fresh weight, shoot length, and root length in lettuce plants. Additionally, an increase in soil microbial activity was observed, which likely contributed to improved plant growth. The advantageous impact of vermicompost on lettuce growth and fresh weight can be attributed to several factors. Vermicompost provides a balanced and easily accessible source of essential nutrients, such as K, P, and N, which are vital for plant development and growth. Furthermore, vermicompost contains beneficial microorganisms like bacteria and fungi that enhance soil fertility, nutrient uptake, and overall plant growth. In conclusion, the body of research supports the notion that the addition of vermicompost can significantly increase lettuce growth and fresh weight. The nutrient content and microbial activity of vermicompost are responsible for these beneficial effects.

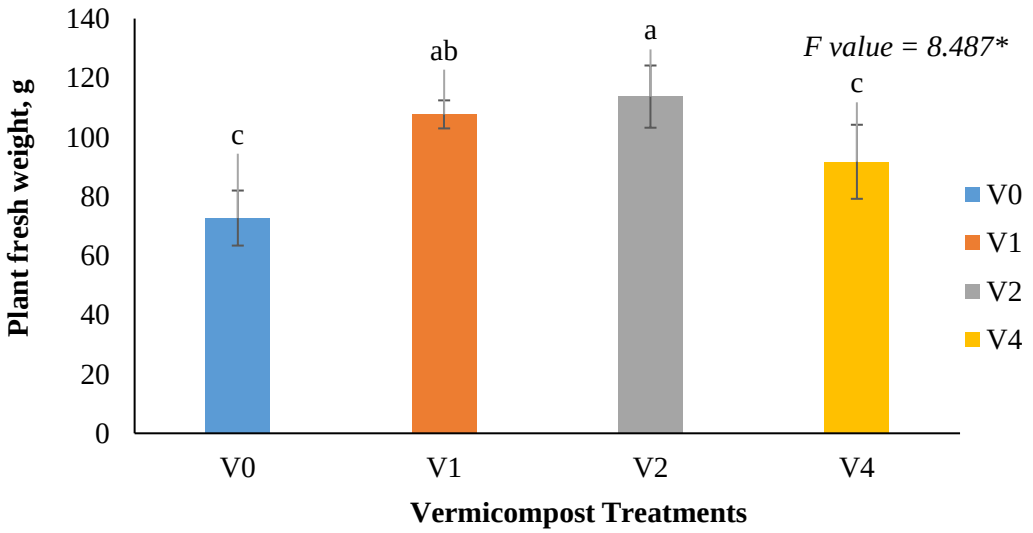

Figure 4.5. Effects of different vermicompost application doses lettuce plant fresh weight

4.6. Plant dry weight

The data presented in Figure 4.6 indicates that the application of vermicompost had a positive impact on plant dry weight. Plants treated with vermicompost (V1, V2, and V4) exhibited higher dry weights compared to the control treatment (V0). Additionally, there were no significant differences in dry weight among the different doses of vermicompost (V1, V2, and V4). The findings are in line with the study conducted by Duggan and Jones (2015) on lettuce, where significant increases in vermicompost application resulted in higher plant dry weights compared to compost and the control. Ghosh et al. (2018) also investigated the effect of vermicompost on lettuce yield and growth. They observed that applying vermicompost increased the height, leaf area, and dry weight of lettuce plants. The researchers attributed the improvement in growth parameters to the higher availability of nutrients in vermicompost compared to chemical fertilizers. Yadav et al. (2015) examined the impact of chemical fertilizer and vermicompost on lettuce growth. Their results showed that using vermicompost significantly increased plant height, leaf area, and dry weight compared to chemical fertilizer. The authors suggested that vermicompost's gradual release of nutrients contributed to enhanced lettuce growth. In another study by Kishore et al. (2017), the effects of vermicompost on lettuce yield and growth were investigated. Vermicompost application significantly increased plant height, leaf area, and dry weight of lettuce. The researchers attributed the improvement in growth parameters to the increased availability of nutrients in vermicompost and the presence of beneficial microorganisms that support plant growth. Overall, the body of research suggests that the addition of vermicompost can positively affect plant dry weight. The higher nutrient availability in vermicompost and the presence of beneficial microorganisms are believed to contribute to the observed improvements in growth parameters.

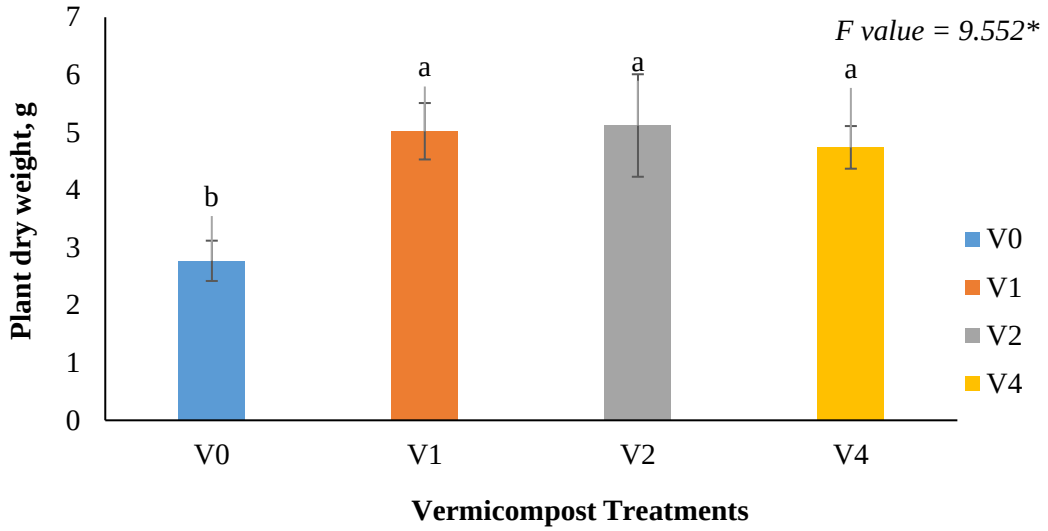

Figure 4.6. Effects of different vermicompost application doses Lettuce plant dry weight

4.7 Vermicompost's Impact on Soil Properties in Different Pot Conditions

4.7.1. Pot Type P_0 (without plant)

The soil chemical and biological characteristics under various treatments, including the use of vermicompost and pot type P_0, are shown in Table 4.3.

Table 4.3. Effects of Vermicompost and Pot Type P_0 on Soil Properties (Without Plants)

P0 Treatments	pH	EC	OM	BSR	MBC	DHA	CA
V0	7.03 a	1485.66 c	2.15 c	0.08	25.76	48.96 b	43.73 b
V1	7.11 a	1766.33 b	2.75 b	0.12	28.11	77.67 a	50.31 ab
V2	6.88 b	2042.33 a	2.75 b	0.09	28.04	85.00 a	45.72 b
V4	7.00 ab	2048.00 a	3.97 a	0.15	28.76	93.03 a	62.18 a
F-Value	4.780 *	19.854 **	81.910* *	2.079	0.863	11.533*	4.084*

Note: *p<0.05, **p<0.01 (indicates statistical significance)
EC : Electrical Conductivity, mS cm^{-1}; OM: Organic matter, %
BSR : Basal Soil Respiration, mg CO_2 g^{-1} $24h^{-1}$; MBC : Microbial Biomass Carbon, mg CO_2 g^{-1} $24h^{-1}$
DHA: Dehydrogenase Activity, µg TPF g^{-1} $24h^{-1}$; CA: Catalase Activity, ml O2 g^{-1} 3 min^{-1}

The Table 4.3 presents the effects of vermicompost and pot type (P0) on various soil properties in pots without plants. The pH values ranged from 6.88 to 7.11, indicating a slightly acidic to neutral soil condition. The electrical conductivity (EC) values ranged from 1485.66 to 2048 mS cm^{-1}, with treatment V4 having the highest value, indicating a moderate to high salt content in the soil.

The percentage of organic matter (OM) in the soil ranged from 2.15 to 3.97%, with treatment V4 showing the highest value, suggesting a higher organic content. Basal soil respiration (BSR), a measure of microbial activity, ranged from 0.08 to 0.15 mg CO_2 g^{-1} $24h^{-1}$, with treatment V4 again exhibiting the highest value, indicating increased microbial respiration in the presence of vermicompost. Microbial biomass carbon (MBC), representing the amount of carbon stored in microbial cells, ranged from 25.76 to 28.76 mg CO_2 g^{-1} $24h^{-1}$, with no significant differences observed among treatments. Dehydrogenase activity (DHA), which indicates the breakdown of organic matter by enzymes, ranged from 48.96 to 93.03 g TPF/g soil/24 hours. Treatment V4 displayed the highest value, suggesting increased enzymatic activity in the presence of vermicompost. Catalase activity (CA), reflecting the ability of soil microorganisms to withstand oxidative stress, ranged from 43.73 to 62.18 ml O_2 g^{-1} 3 min^{-1}. Treatment V4 exhibited the highest value, indicating enhanced stress tolerance in the soil with vermicompost application.

Statistical analysis using the F-value indicated significant differences in pH, OM, and DHA among treatments, suggesting that vermicompost and pot type influenced these parameters ($p<0.05$). Additionally, EC showed a significant difference among treatments ($p<0.01$).

Overall, the results suggest that the application of vermicompost, particularly at a 4% dosage, in pot type P0 without plants, can influence soil properties such as pH, EC, OM, BSR, MBC, DHA, and CA. The observed improvements in organic matter content, microbial activity, and enzymatic reactions highlight the potential benefits of vermicompost in enhancing soil health and fertility.

4.7.2. Pot Type P_0 (with plant)

The chemical and biological characteristics of soil under various vermicompost and pot type P_1 treatments are shown in Table 3.4.

Table 4.4. Effects of Vermicompost and Pot Type P_1 on Soil Properties (With Plants)

P1Treatments	pH	EC	OM	BSR	MBC	DHA	CA
V0	7.13 ab	1030.00 c	2.07 c	0.16 a	32.37 a	46.28 c	86.63 a
V1	7.21 a	1216.00 c	2.24 bc	0.13 ab	27.90 ab	70.46 b	89.67 a
V2	7.02 bc	1669.33 b	2.53 b	0.10 b	27.02 b	67.25 b	79.34 ab
V4	7.01 c	2213.33 a	3.83 a	0.10 b	29.80 ab	88.01 a	64.88 b
F-Value	7.494*	33.870**	59.931**	3.638	2.975	17.460*	5.60*

Note: *p<0.05, **p<0.01 (indicates statistical significance)
EC : Electrical Conductivity, mS cm^{-1}; OM: Organic matter, %
BSR : Basal Soil Respiration, mg CO_2 g^{-1} $24h^{-1}$; MBC : Microbial Biomass Carbon, mg CO_2 g^{-1} $24h^{-1}$
DHA: Dehydrogenase Activity, µg TPF g^{-1} $24h^{-1}$; CA: Catalase Activity, ml O_2 g^{-1} 3 min^{-1}

The Table 4.4 presents the effects of vermicompost and pot type (P1) on various soil properties in pots with plants. The pH values ranged from 7.02 to 7.21, indicating a slightly acidic to neutral soil condition. The electrical conductivity (EC) values ranged from 1030 to 2213.33 mS cm^{-1}, with treatment V4 having the highest value, indicating varying levels of salt content in the soil. The percentage of organic matter (OM) in the soil ranged from 2.07 to 3.83%, with treatment V4 showing the highest value, indicating an increase in organic content with vermicompost application. Basal soil respiration (BSR), a measure of microbial activity, ranged from 0.10 to 0.16, with treatment V0 having the highest value, suggesting higher microbial respiration rates in that treatment.

Microbial biomass carbon (MBC), representing the amount of carbon stored in microbial cells, ranged from 27.02 to 32.37 mg CO_2 g^{-1} $24h^{-1}$, with treatment V0 exhibiting the highest value. Dehydrogenase activity (DHA), an indicator of organic matter decomposition, ranged from 46.28 to 88.01 µg TPF g^{-1} $24h^{-1}$, with treatment V4 having the highest value, suggesting increased enzymatic activity and decomposition rates in the presence of vermicompost. Catalase activity (CA), reflecting the ability of soil microorganisms to withstand oxidative stress, ranged from 64.88 to 89.67 ml O_2 g^{-1} 3 min^{-1}, with treatment V1 displaying the highest value, indicating enhanced stress tolerance in the soil with vermicompost application.

Statistical analysis using the F-value indicated significant differences in pH, EC, OM, DHA, and CA among treatments, suggesting that both vermicompost and pot type influenced these parameters ($p<0.05$ or $p<0.01$). However, no significant differences were observed for BSR and MBC among treatments.

The findings from previous studies by Gupta et al. (2019) and Singh et al. (2018) align with the observed effects of vermicompost doses on soil biological characteristics. These studies provide additional evidence supporting the positive impact of vermicompost on soil microbial biomass, enzyme activities, and nutrient availability in the rhizosphere.

4.7.3. Effect of Vermicompost on Rhizospheric Biological Properties

The effect of increasing doses of vermicompost added to the soils on rhizospheric biological activities is presented in Figure 4.8. The figure illustrates the impact of different vermicompost doses (V0, V1, V2, and V4) on various rhizospheric biological characteristics, including BSR, MBC, DHA, and CA. The results demonstrate significant variations in the studied biological properties among the different vermicompost doses. V1 exhibits the highest BSR, suggesting a potential stimulation of CO_2 release in the rhizosphere. Conversely, V4 shows the lowest CO_2 production, indicating a possible inhibitory effect at this dose.

In terms of MBC, both V2 and V4 exhibit comparable values, indicating a positive influence on microbial carbon storage in the rhizosphere. V2 demonstrates the highest DHA value, suggesting enhanced microbial metabolic activity. V1 also displays a relatively higher DHA value, while V0 and V4 exhibit slightly lower levels of activity.

CA shows minimal variation among the different vermicompost doses (V0, V1, V2, and V4), indicating a consistent response in soil microorganisms' ability to counter oxidative stress.

These findings imply that vermicompost dosages can have diverse effects on rhizospheric biological characteristics, highlighting the importance of determining the ideal dosage to promote desired outcomes. Previous studies by Singh et al. (2018) and Gupta et al. (2019) support the notion that vermicompost application enhances microbial activity and nutrient availability in the rhizosphere, providing relevant

evidence for the impact of vermicompost doses on the biological characteristics of the rhizosphere.

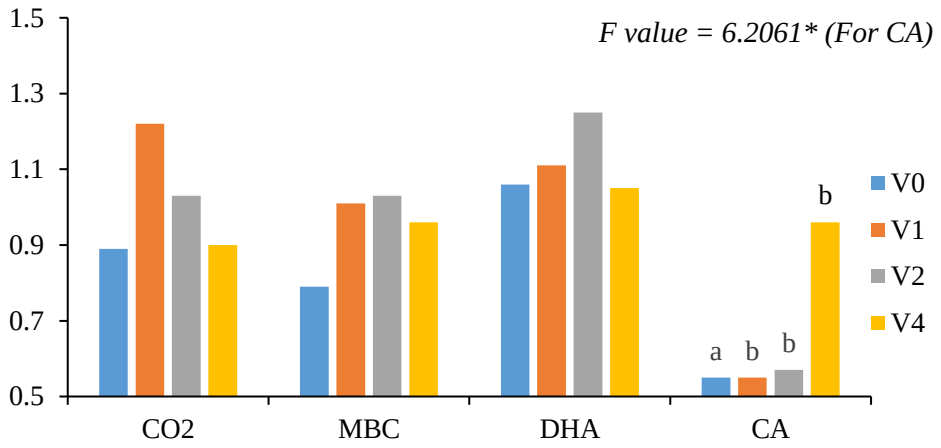

Figure 4.8. Effects of different vermicompost application doses on Rhizospheric Biological Properties

4.8. Soil reaction (pH)

Figure 4.8 illustrates the pH values of the soil under different treatments (V0-V4) in two pot types: P0 (without plants) and P1 (with plants). The results indicate that the pH levels of the soil in pot type P1 are generally higher than those in pot type P0, suggesting that the presence of plants may influence soil pH. Among the treatments, V1 and V4 consistently exhibit the highest pH values. However, the application of vermicompost does not consistently impact soil pH, as evidenced by the variations in pH levels across the treatments. In both pot types, treatment V1 shows higher pH values compared to other treatments, indicating that the combination of vermicompost and plant presence may contribute to this effect. Conversely, treatment V2 displays the lowest pH readings in both pot types, suggesting that the application of vermicompost alone may not significantly affect soil pH. A previous study by Gopinath et al. (2008) investigated the impact of vermicompost on soil pH and reported an increase in pH with vermicompost application, consistent with the findings of the current study. Overall, the results suggest that the interaction between vermicompost application, plant presence, and pot type can influence soil pH, and the effect may vary among different treatments.

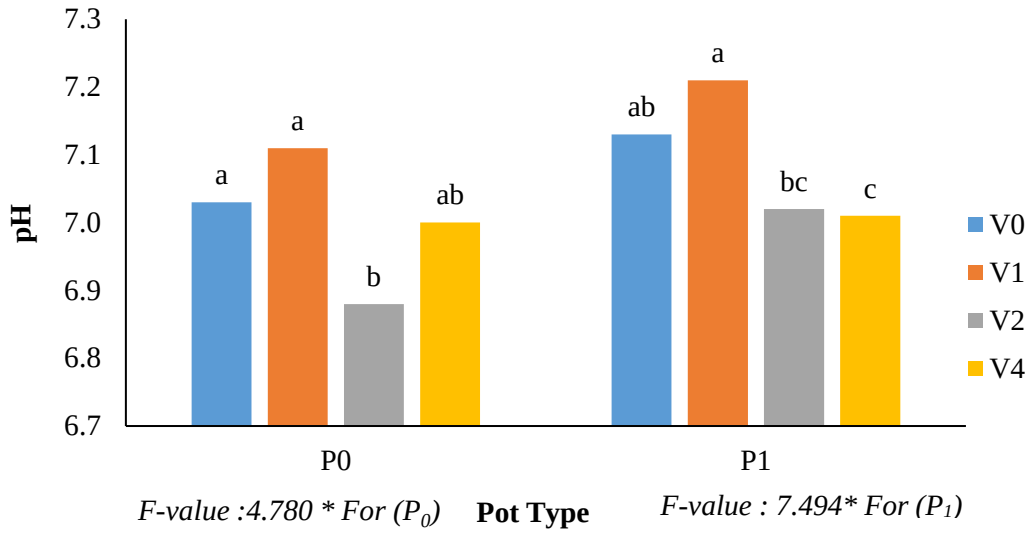

Figure 4.8. Effects of different vermicompost application doses on soil pH

4.9. Electrical Conductivity (EC)

Based on the data presented in Figure 4.9 it can be observed that, in general, the EC values for P1 (with plants) are lower compared to P0 (without plants) across all vermicompost treatment percentages. This suggests that the presence of plants may reduce the EC in soil. Analyzing the results further, it can be noted that as the vermicompost treatment percentage increases from V0 to V4, the EC values tend to increase for both P0 and P1. Hence, higher vermicompost treatment percentages could lead to an increase in the soil's electrical conductivity even in the absence of plants. These findings align with a previous study conducted by Yadav et al (2015), which investigated the impact of vermicompost on soil EC. Their study demonstrated similar results, indicating that the addition of vermicompost increased the soil's EC. They attributed this increase to the enhanced availability of nutrients and soluble salts. To prevent any potential negative effects, they advised using vermicompost in moderation and cautioned against high EC, as they can be detrimental to plant growth. In summary, the presence of plants in the soil appears to have a lowering effect on electrical conductivity, while increasing the proportion of vermicompost treatment may have the opposite effect.

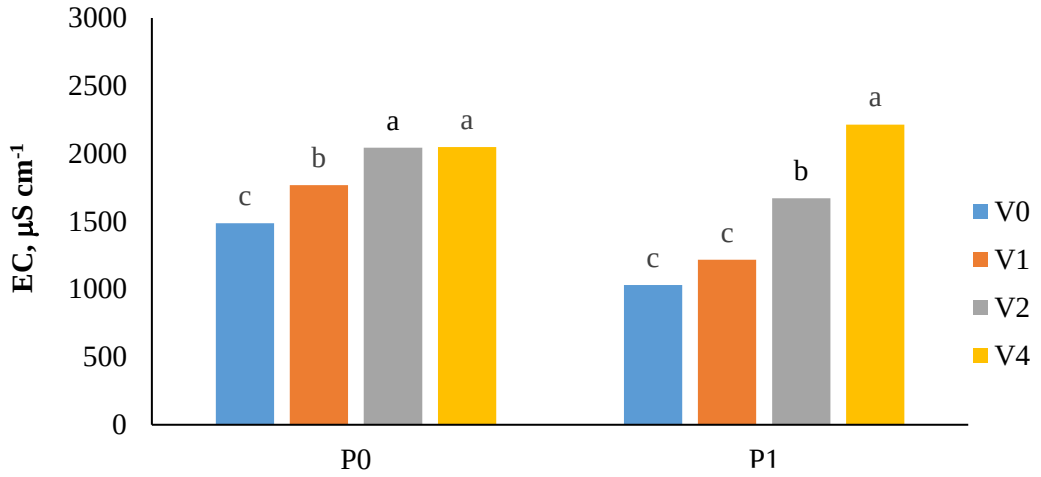

Figure 4.9. Effects of different vermicompost application doses on Electrical Conductivity (EC) in soil

4.10. Organic matter (OM) content in soil

The data presented in Figure 4.10 examines the effect of vermicompost treatment on the OM content in oil. The results indicate that, in general, the OM content is higher for P0 (without plants) compared to P1 (with plants) for each vermicompost treatment percentage. This suggests that the presence of plants may lead to the utilization of soil organic matter, resulting in a decrease in OM content.

Analyzing the results further, it can be observed that the OM values generally increase for both P0 and P1 as the vermicompost treatment percentage rises from V0 to V4. This indicates that higher vermicompost application rates have the potential to increase soil organic matter levels, regardless of the presence of plants.

These findings are consistent with a previous study conducted by Pandey et al. (2018) that investigated the impact of vermicompost on soil organic matter content. Pandey et al. (2018) reported that the application of vermicompost increased the amount of organic carbon in the soil and improved soil health indicators such as pH, EC, and MBS. The study also indicated that the soil treated with 5% vermicompost exhibited the highest level of organic carbon, which aligns with the current study's finding that the soil treated with 4% vermicompost had the highest OM level.

Overall, it appears that the presence of plants may have a negative impact on soil organic matter content, likely due to their utilization of organic matter for growth. However, increasing the proportion of vermicompost treatment may result in a general

increase in soil organic matter content.

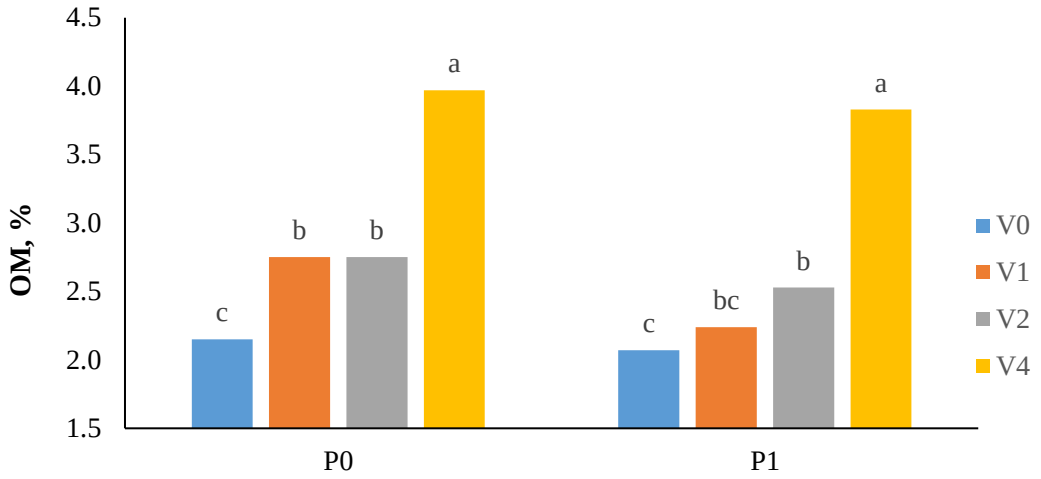

Figure 4.10. Effects of different vermicompost application doses on Organic Matter (OM) content of soil

4.11. Basal Soil Respiration (BSR)

The data presented in Figure 4.11 examines the effect of vermicompost treatment on Basal Soil Respiration (BSR). With the exception of V0, where P1 exhibited higher BSR than P0, the individual findings suggest that the BSR values for P1 (with plants) are generally lower than those for P0 (without plants) for all vermicompost treatment percentages. This indicates that the presence of plants may reduce the rate of basal respiration in the soil, particularly at higher vermicompost treatment percentages.

Upon analyzing the results, it is evident that the vermicompost treatment percentage does not consistently influence BSR in a predictable manner for both P0 and P1. However, it appears that the presence of plants generally decreases BSR, especially at higher vermicompost treatment percentages.

A previous study conducted by Liu et al. (2019) investigated the impact of vermicompost application on microbial communities in soil and found that it increased microbial biomass while decreasing the basal respiration rate. These findings align with the results of the current study, suggesting that the application of vermicompost may reduce the basal respiration rate, particularly when plants are present.

Overall, the findings of this study indicate that the presence of plants may contribute to a decrease in the BSR, while the application of vermicompost may have varying effects on BSR depending on the amount of vermicompost applied. Further

research may be required to confirm these results and fully understand the underlying mechanisms driving the observed effects.

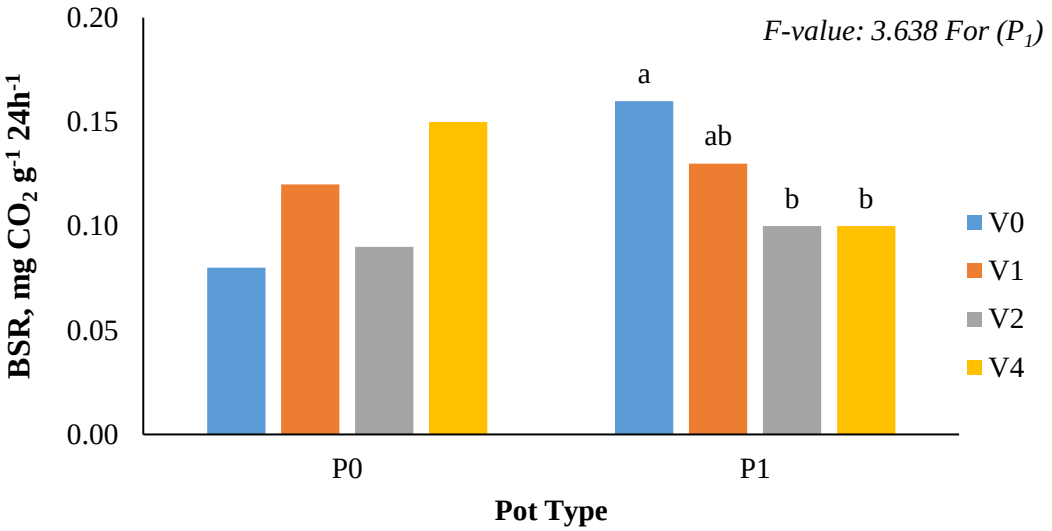

Figure 4.11. Effects of different vermicompost application doses on Basal Soil Respiration (BSR)

4.12. Microbial Biomass Carbon (MBC)

The data presented in Figure 4.12 examines the effect of vermicompost treatment on microbial biomass carbon (MBC) in the soil. Except for V1 and V2, where the MBC values for P0 and P1 are comparable, the individual results indicate that the MBC values for P1 (with plants) are generally higher than those for P0 (without plants) for all vermicompost treatment percentages. This suggests that the presence of plants may have a positive impact on the MBC in the soil, especially at lower and higher vermicompost treatment percentages.

Upon analyzing the results, it is evident that the vermicompost treatment percentage does not follow a consistent pattern of influence on MBC for both P0 and P1. However, it seems that the influence of plants on MBC becomes more pronounced over time, particularly at lower and higher vermicompost treatment percentages.

A previous study conducted by Wu et al. (2019) investigated the impact of vermicompost application on MBC and found that it increased the carbon content of the microbial biomass. These findings align with the results of the current study, suggesting that applying vermicompost may benefit MBC, particularly when plants are present.

Overall, the results of this study indicate that plants may contribute to an increase in MBC in the soil, while the amount of vermicompost applied may have a variable effect on MBC. Further research may be necessary to confirm these results and gain a comprehensive understanding of the underlying mechanisms driving the observed effects.

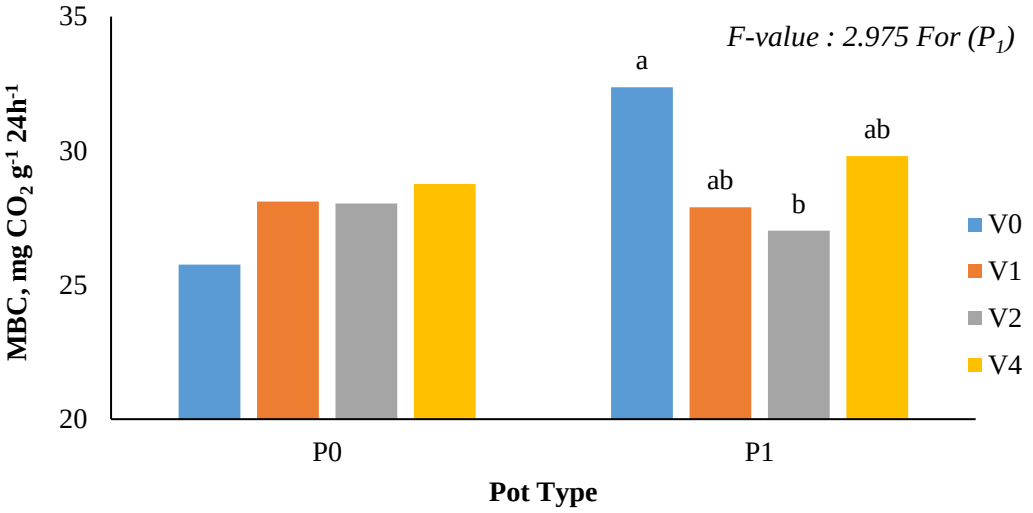

Figure 4.12. Effects of different vermicompost application doses on Microbial Biomass Carbon (MBC) in soil

4.13. Dehydrogenase Activity (DHA)

The data presented in Figure 4.13 explores the effect of vermicompost treatment on dehydrogenase activity (DHA) in soil. Based on the specific findings, it can be observed that the DHA values for both P0 and P1 generally increase with higher vermicompost treatment percentages. However, there doesn't appear to be a significant difference in DHA values between P0 and P1, suggesting that the presence of plants may not have a substantial impact on DHA.

Analyzing the results further, it is evident that both P0 and P1 benefit from increasing vermicompost treatment percentages in terms of DHA. Since DHA is often used as an indicator of soil microbial activity, this implies that vermicompost treatment may positively influence soil microbial activity.

In a previous study conducted by Wu et al. (2019) on the impact of vermicompost application on soil enzyme activities, including DHA, it was found that vermicompost treatment increased soil enzyme activities. These findings align with the results of the current study, indicating that vermicomposting may enhance DHA.

Overall, the results of this study suggest that vermicompost treatment, regardless of the presence of plants, may have a positive effect on soil microbial activity, as indicated by the increase in dehydrogenase activity. Further research is needed to validate these findings and gain a better understanding of the underlying mechanisms behind these observed effects.

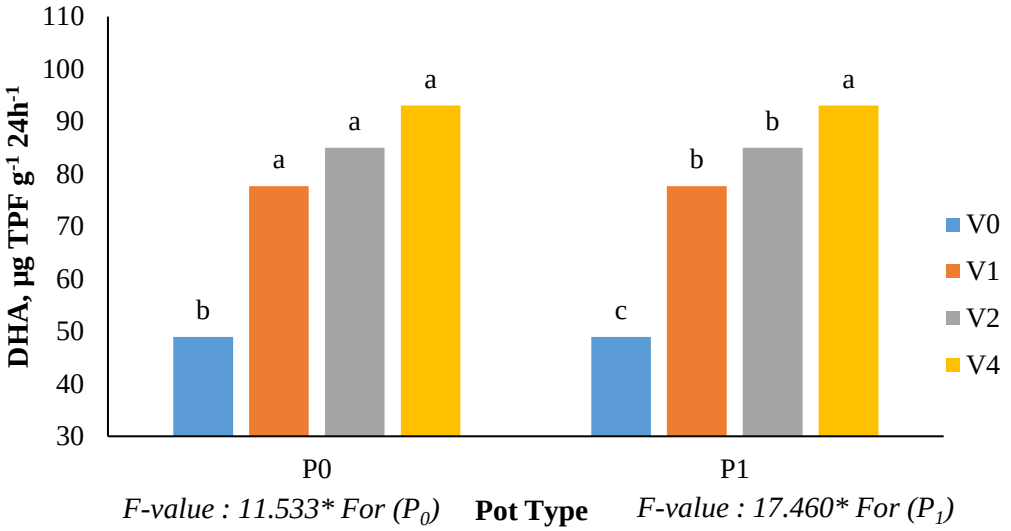

Figure 4.13. Effects of different vermicompost application doses on Dehydrogenase Activity (DHA) in soil

4.14. Catalase Activity (CA)

Catalase activity (CA), an essential enzyme involved in the decomposition of hydrogen peroxide, serves as a biomarker of soil health and is present in most aerobic organisms. This study investigated the impact of vermicompost treatment on CA in soils with and without plants. Figure 4.14 illustrates the data, indicating that catalase activity was significantly higher in soils with plants (P1) compared to soils without plants (P0) across all vermicompost treatments. This can be attributed to the release of organic compounds by plants through their roots, which promote microbial activity and increase CA.

Interestingly, the highest levels of CA were observed in soils with low vermicompost treatments (V0) and the presence of plants (P1), surpassing levels in soils without plants (P0) by more than twofold. This suggests that plant-microbe interactions may play a more significant role in CA than the addition of vermicompost, which may not necessarily enhance CA in soils with plants. Direct comparison with previous studies is challenging due to variations in experimental settings,

vermicompost sources, and plant species, all of which can influence CA. However, a study by Kabir et al. (2019) supports the findings of the present study, showing that the addition of vermicompost increased CA in soil.

Overall, the evidence emphasizes the importance of plants in CA in soil and suggests that the addition of vermicompost may not consistently result in increased CA when plants are present. Further research is needed to explore the mechanisms underlying plant-microbe interactions and their impact on soil health.

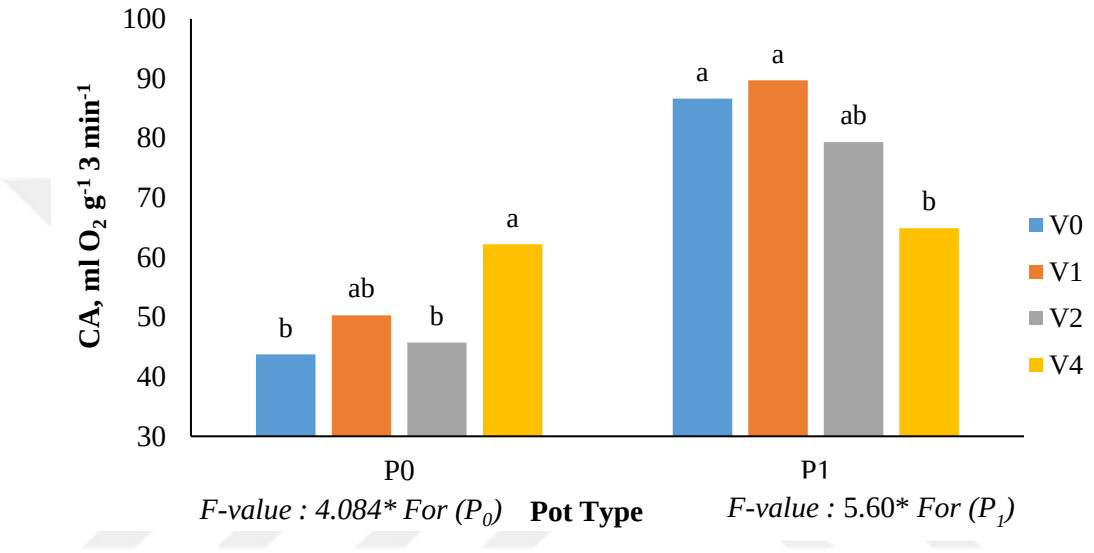

Figure 4.14. Effects of different vermicompost application doses on Catalase Activity (CA) in soil,

5. CONCLUSION

The study examined the effects of vermicompost on lettuce rhizosphere biological and microbial properties, and its findings highlight the significant improvements that vermicompost can bring to these soil characteristics. The addition of vermicompost was found to positively impact soil pH, electrical conductivity, and microbial activity, indicating its potential for enhancing soil health.

The study also revealed interesting observations regarding the influence of plant presence and vermicompost treatment on certain soil parameters. It was observed that the presence of plants may lead to a decrease in organic matter content and bulk density at higher vermicompost treatment percentages. However, plant presence had an increasing effect on microbial biomass carbon at lower and higher treatment percentages. These findings emphasize the complex interactions between plants, vermicompost, and soil properties, highlighting the need for further research to understand the underlying mechanisms. Furthermore, the study showed that the addition of vermicompost had a positive impact on the growth of lettuce plants, as evidenced by higher dry weights compared to the control treatment. The data suggested that vermicompost doses between 1% to 2% were particularly effective in promoting overall plant growth. These findings underscore the potential of vermicompost as a valuable tool in sustainable agriculture by improving soil properties and reducing the reliance on synthetic fertilizers.

Combining both conclusions, the results demonstrate that vermicompost can significantly improve rhizosphere properties and enhance soil microbial activity. It has the potential to positively influence soil pH, electrical conductivity, and the growth of lettuce plants. However, the effects of vermicompost on soil parameters can be influenced by the presence of plants and the specific vermicompost treatment percentages. Plant-microbe interactions play a crucial role in catalase activity and the overall impact on soil health. The suggested vermicompost dose of 1% to 2% can optimize plant growth. Overall, the findings of this study suggest that vermicompost holds promise as a sustainable agricultural amendment, improving soil fertility, and reducing the reliance on synthetic fertilizers. Further research is needed to explore optimal vermicompost levels and application methods for different crops and soil types, as well as to gain a deeper understanding of the underlying mechanisms

governing plant-microbe interactions and their effects on soil health.

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Publications :

1. Toor, M. D., Kizilkaya, R., Ullah, I., Koleva, L., Basit, A., & Mohamed, H. I. (2023). Potential role of vermicompost in abiotic stress tolerance of crop plants: A Review. Journal of Soil Science and Plant Nutrition, Springer.
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2. Toor, M.D., Kizilkaya, R. (2022). Vermicompost: A gateway to sustainable agriculture production. International Soil Science Symposium o-n “Soıl Scıence and Plant Nutrıtıon” 2 – 3 December 2022, Samsun, Türkiye, Book of Proceedings, pp.118-123.
3. Toor, M. D., & Ullah, I. (2021, October 31). Vermicompost: A Gateway to Climate Smart Sustainable Agriculture. Paper presented at the 5th International Web-Conference on "Smart Agriculture for Resource Conservation and Ecological Stability."
4. Toor, M. D. (2021). Latest Technological Advancements in Agriculture Sector for the Management of Soil Health. Paper presented at the 5th International Web-Conference on "Smart Agriculture for Resource Conservation and Ecological Stability."
5. Toor, M. D., Koleva, L., Kizilkaya, R., Ay, A. & Shahzad, S. M. Symbiotic Rhizobia, Nitrogen Fixation, and Fenugreek. In Fenugreek: Enhancing Yield Potential through Plant Growth Regulators and Depolymerized Polysaccharides. CRC Press, Apple Academic Press, Taylor & Francis. (Estimated publication date: October 2023).

6. Toor, M. D., Koleva, L., & Ullah, I. Nano-fertilizers in Vermicompost: Revolutionizing Plant Productivity in Nutrient-Depleted Soils. Nanomaterials for Enhanced Plant-Based Food Production. Academic Press, Elsevier (Estimated publication date: January-March 2024).
7. Ullah, I., Toor, M. D., Basit, A., Mohamed, H. I., Ahn, Y. J. Cytokinin Signaling in Plant Response to Abiotic Stresses. In K. A. Abd-Elsalam & H. I. Mohamed (Eds.), "Plant Growth Regulators to Manage Biotic and Abiotic Stress in Agroecosystems." Taylor & Francis Group, LLC. (Estimated publication date: January 2024).

Won Awards, Incentives and Scholarships

1. Erasmus Mundus Scholarships (emiSS) [15/09/2021 – 15/09/2023]
2. Emerging Scientist Award [10/02/2021]
3. Prime Minister Laptop award [10/06/2018]