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

THE POTENTIAL USE OF OLIVE SOLID WASTE AND ITS BOTTOM ASH TO IMPROVE SOIL CHARACTERISTICS AND WHEAT YIELD

Master's Thesis

Sinan Rushdi Ahmad ABU AL HAYJA

I. Supervisor
Prof. Dr. Coşkun GÜLSER

II. Supervisor

Prof. Dr. Tomasz ZALESKI

SAMSUN
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2023

ACCEPTANCE AND APPROVAL OF THE THESIS

The study entitled **“THE POTENTIAL USE OF OLIVE SOLID WASTE AND ITS BOTTOM ASH TO IMPROVE SOIL CHARACTERISTICS AND WHEAT YIELD”** prepared by **Sinan ABU AL HAYJA**, and supervised by **Prof. Dr. Coskun GULSER**, and **Prof. Dr. Tomasz ZALESKI**, was found successful and unanimously accepted by committee members as Master thesis, following the examination on the date 15.8.2023 .

	Title Name SURNAME **University** **Department/Art**	**Final Decision**
Chairman	Prof. Dr. Coskun GULSER Ondokuz Mayis University Department of Soil Science and Plant Nutrition	☒ Accept ☐ Reject
Member	Prof. Dr. Andon ANDONOV Agricultural University Plovdiv Department of Plant Physiology, Biochemistry and Genetics	☒ Accept ☐ Reject
Member	Prof. Dr. Ridvan KIZILKAYA Ondokuz Mayis 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.

Is Ethics Committee Necessary?

Yes ☐ (If it necessary, please add appendices.)

No ☒

13 /07 / 2023
Sinan Rushdi Ahmad ABU AL HAYJA

DECLARATION OF THE THESIS STUDY ORIGINALITY REPORT

Thesis Title : THE POTENTIAL USE OF OLIVE SOLID WASTE AND ITS BOTTOM ASH TO IMPROVE SOIL CHARACTERISTICS AND WHEAT YIELD

As a result of the originality report taken by me from the plagiarism detection program on 14/07 /2023 for the thesis titled above;

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ÖZET

ZEYTİN KATI ATIĞI VE ALT KÜLÜNÜN TOPRAK ÖZELLİKLERİNİN VE BUĞDAY VERİMLİLİĞİNİN İYİLEŞTİRİLMESİ AMACIYLA KULLANILABİLİRLİĞİ

Sinan Rushdi Ahmad ABU AL HAYJA
Ondokuz Mayıs Üniversitesi
Lisansüstü Eğitim Enstitüsü
Toprak Bilimi Ve Bitki Besleme Ana Bilim Dalı
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Danışman: Prof. Dr. Coşkun GÜLSER
II. Danışman: Prof. Dr. Tomasz ZALESKI

Bu çalışma, zeytin katı atığı ve taban külünün toprağın fiziksel ve kimyasal özelliklerini iyileştirmek için toprak düzenleyici olarak potansiyel kullanımını değerlendirmeyi ve bunların su stresi ve normal koşullar altında buğday verimi üzerindeki etkilerini değerlendirmeyi amaçlamaktadır. 48 saksı, 2 kg kumlu tınlı ve killi toprakla doldurulmuş, su stresi koşullarını temsil eden, toprak tarla kapasitesinin %100'ü ve bitkinin kullanılabilir su kapasitesinin %30'u olmak üzere iki sulama uygulamasına bölünmüştür. Topraklara pirina (OP), pirina dip külü (OPBA) ve her ikisinin karışımı (OP+OPBA) olmak üzere üç tip toprak uygulaması yapılmıştır. Her tedavi kombinasyonu üç kez tekrarlandı. Çalışma, bu işlemlerin toprağın fiziksel ve kimyasal özellikleri üzerindeki etkisinin yanı sıra buğday büyümesi ve verimi üzerindeki etkilerini araştırmaya odaklanmaktadır. Bulgular, zeytin atığı ürünlerinin sürdürülebilir toprak iyileştirmeleri olarak potansiyel kullanımının anlaşılmasına, özellikle de toprak kalitesini iyileştirirken su stresinin mahsul üretimi üzerindeki olumsuz etkilerinin azaltılmasına katkıda bulunacaktır.

Anahtar Sözcükler: Toprak özellikleri, verim, buğday, organik atıklar, pirina, dip külü, su stresi, toprak kalitesi

ABSTRACT

THE POTENTIAL USE OF OLIVE SOLID WASTE AND ITS BOTTOM ASH TO IMPROVE SOIL CHARACTERISTICS AND WHEAT YIELD

Sinan Rushdi Ahmad ABU AL HAYJA
Ondokuz Mayıs University
Institute of Graduate Studies
Department of Soil Science and Plant Nutrition
Master, July/2023
Supervisor: Prof. Dr. Coskun GÜLSER
II. Supervisor: Prof. Dr. Tomasz ZALESKI

This study aims to evaluate the potential utilization of olive solid waste and its bottom ash as soil amendments to enhance soil physical and chemical characteristics and assess their effects on wheat yield under water stress and normal conditions. 48 pots were filled with 2 kg of sandy loam and clay soils, divided into two irrigation treatments 100% of the soil field capacity and 30% of the plant available water capacity, representing water stress conditions. Three types of soil applications, including olive pomace (OP), olive pomace bottom ash (OPBA), and a mixture of both (OP+OPBA), were applied to the soils. Each treatment combination was replicated three times. The study focuses on investigating the impact of these treatments on soil physical and chemical properties, as well as their influence on wheat growth and yield. The findings will contribute to understanding the potential use of olive waste products as sustainable soil amendments, particularly in mitigating the adverse effects of water stress on crop production while improving soil quality.

Keywords: Soil properties, yield, wheat, organic wastes, olive pomace, bottom ash, water stress, soil quality

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CONTENTS

SYMBOLS AND ABBREVIATIONS

100Ir	: 100% Irrigation of the Soil Field Capacity
30Ir	: 30% Irrigation of the Plant Available Water
AS	: Aggregate Stability
AWP	: Plant Available Water
CEC	: Cation Exchange Capacity
CF	: Crust Formation
DR	: Dispersion Ratio
EC	: Electrical Conductivity
FC	: Field Capacity
GP	: Germination Percentage
HI	: Harvest Index
OM	: Organic Matter
OP	: Olive Pomace
OP+OPBA	: Mixture of Olive Pomace and its Bottom Ash
OPBA	: Olive Pomace Bottom Ash
Pb	: Soil Bulk Density
Pd	: Soil Particle Density
pH	: Soil Reactions
PWP	: Permanent Wilting Point
SSI	: Structure Stability Index
WUE	: Water Use Efficiency
Φ	: Soil Porosity

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1. INTRODUCTION

1.1. Organic Waste Production

Organic waste production is a significant environmental concern globally, as it poses various challenges to sustainable waste management and has implications for climate change, resource depletion, and public health. Organic waste refers to any waste material that originates from living organisms or contains organic compounds. This includes food waste, agricultural residues, yard trimmings, sewage sludge, and animal manure.

The production of organic waste has been on the rise due to several factors. Firstly, population growth and urbanization have led to increased consumption patterns and consequently higher amounts of food waste generated. According to the Food and Agriculture Organization (FAO), approximately one-third of all food produced for human consumption is lost or wasted globally each year, amounting to about 1.3 billion tons.

Secondly, changes in dietary habits, particularly the shift towards a more meat-intensive diet, have contributed to an increase in organic waste generation. Livestock production generates significant amounts of animal manure, which can be challenging to manage effectively.

Furthermore, rapid industrialization and agricultural intensification have resulted in the generation of substantial quantities of organic waste. Agricultural residues, such as crop residues and by-products from agro-industries, contribute to this waste stream.

The mismanagement of organic waste has numerous adverse environmental impacts. When organic waste decomposes in landfills under anaerobic conditions, it produces methane, a potent greenhouse gas that contributes to climate change. Moreover, the inadequate treatment of organic waste can contaminate water bodies and soil, posing risks to human and ecosystem health.

Addressing the issue of organic waste requires a comprehensive approach that includes waste reduction, recycling, and proper disposal. Implementing strategies such as composting, anaerobic digestion, and biomethanation can help convert organic waste into valuable resources like compost and biogas. These practices not only reduce greenhouse gas emissions but also provide opportunities for energy generation and soil improvement.

To combat organic waste production effectively, it is crucial to adopt sustainable waste management practices at various levels, including households, businesses, and governments. This involves promoting awareness about food waste reduction, implementing effective collection and segregation systems, and investing in appropriate infrastructure for waste treatment and recycling.

1.2. Numbers of Olive Oil and Olive Solid Waste and Olive Wastewater Production in the World

Olive oil production is a significant global industry, and along with it comes the generation of olive solid waste and olive wastewater. Understanding the scale of olive oil production and the corresponding waste streams is essential for effective waste management and resource utilization.

The production of olive oil worldwide has seen significant growth in recent years. According to the International Olive Council (IOC), global olive oil production reached approximately 3.4 million tons in the 2020/2021 harvest season (IOC, 2021).

With the production of olive oil comes the generation of olive solid waste, also known as olive pomace. Olive pomace consists of the residual solid materials remaining after oil extraction. The exact quantity of olive pomace produced globally can vary depending on various factors, including olive varieties, extraction methods, and regional practices. However, it is estimated that for every ton of olive oil produced, approximately 4-8 tons of olive pomace is generated (Morales et al., 2017).

In addition to olive pomace, olive oil production also generates a significant amount of olive wastewater, also known as olive mill wastewater or olive mill effluent. Olive wastewater refers to the liquid fraction that results from the olive oil extraction process. The volume of olive wastewater produced globally is influenced by factors such as olive oil production volumes, water usage during processing, and the efficiency of wastewater treatment systems. It is estimated that olive oil production generates around 2.5-8 liters of wastewater per liter of olive oil produced (Tsapekos et al., 2017).

Proper management of olive solid waste and olive wastewater is crucial to minimize their environmental impact and explore their potential value as resources. Various strategies have been developed to address these waste streams, including composting, anaerobic digestion, and extraction of valuable compounds (Papadopoulos et al., 2021). Implementing effective waste management practices can help mitigate the environmental impact of olive oil production while promoting resource recovery and sustainability.

1.3. Olive Mills Solid Waste

Olive mill solid waste, also known as olive pomace or olive mill waste is the residual by-product generated during the production of olive oil. The extraction process involves crushing and pressing olives to extract the oil, leaving behind significant quantities of waste materials that necessitate proper management (European Commission, 2015).

The production of olive mill solid waste is primarily associated with mechanical extraction methods used in the olive oil industry. This waste comprises three main components: olive pomace (solid residue), olive mill wastewater (liquid fraction), and olive husks (outer skin and stone fragments) (Morales et al., 2017).

The environmental implications of olive mill solid waste are a subject of concern. The high moisture content and organic composition of olive pomace make it susceptible to decomposition, resulting in the release of odorous gases and the potential for groundwater pollution if not appropriately handled. Improper disposal of this waste in landfills can contribute to methane emissions, a potent greenhouse gas (Papadopoulos et al., 2021).

Additionally, olive mill wastewater contains high levels of organic matter, phenolic compounds, and nutrients, which can adversely impact soil and water quality if discharged directly into the environment. The organic load and acidity of the wastewater can deplete oxygen levels in water bodies, leading to detrimental effects on aquatic ecosystems (Tsapekos et al., 2017).

Moreover, the accumulation of olive husks can contribute to air pollution when burned as a disposal method, releasing particulate matter and harmful gases into the atmosphere (Ruiz et al., 2013).

To address the challenges posed by olive mill solid waste, various management approaches have been developed. Composting is a common method wherein the waste is mixed with other organic materials and undergoes controlled decomposition to produce nutrient-rich compost suitable for agricultural use. Utilization of olive pomace and husks as biomass for energy generation through techniques like combustion, gasification, or pyrolysis is another approach (Morales et al., 2017).

Recent research and innovation focus on finding sustainable and economically viable solutions for olive mill solid waste. Anaerobic digestion is one such technology that can convert the waste into biogas for energy production. Additionally, extracting valuable compounds such as polyphenols from the waste for industrial applications has gained attention (Papadopoulos et al., 2021).

Efficient management of olive mill solid waste not only minimizes its environmental impact but also presents opportunities for resource recovery and circular economy practices. Proper waste valorization can reduce waste generation, conserve resources, and promote sustainable practices within the olive oil industry (Ruiz et al., 2013).

1.4. Soil Degradation and the Importance of Soil Amending:

Soil degradation refers to the deterioration of the quality and productivity of soil due to various factors such as erosion, nutrient depletion, contamination, compaction, salinization, acidification, and loss of organic matter. It is a significant global environmental issue that affects agricultural productivity, food security, and ecosystem health. Soil degradation can result from natural processes, but human activities such as deforestation, intensive agriculture, improper land management, and industrialization have accelerated its occurrence.

1.4.1. Importance of Amending Soil

Amending soil is crucial for mitigating soil degradation and ensuring sustainable land use. By improving the quality and fertility of soil, amendments can enhance agricultural productivity, support plant growth, and protect ecosystems. Here are the key reasons why amending soil is important:

1. Enhancing Nutrient Availability: Soil amendments, such as organic matter, compost, and fertilizers, replenish essential nutrients in depleted soils. These nutrients, including nitrogen, phosphorus, and potassium, are vital for plant growth and development. Amending soil with the right balance of nutrients improves crop yields, nutrient uptake efficiency, and overall plant health (Montemurro et al., 2015).

2. Improving Soil Structure and Water Retention: Soil amendments like organic matter improve soil structure by enhancing aggregation and reducing compaction. This allows for better water infiltration and drainage, reducing the risk of erosion and waterlogging. Amended soil can retain moisture more effectively, minimizing the need for irrigation and improving drought resistance (Lal, 2015).

3. Promoting Microbial Activity: Soil amendments can foster beneficial microbial communities in the soil, including bacteria, fungi, and earthworms. These

organisms contribute to nutrient cycling, decomposition of organic matter, and the formation of soil aggregates. By promoting microbial activity, amended soil can improve nutrient availability, disease resistance, and overall soil health (Karlen et al., 1997).

4. Mitigating Soil Erosion: Amending soil with organic matter helps to create a protective layer that reduces soil erosion caused by wind and water. The addition of cover crops, mulching, and soil stabilizers can further prevent erosion and loss of topsoil, preserving soil fertility and preventing sedimentation in water bodies (Lal, 2015).

5. Restoring Degraded Soils: Soil amendments play a crucial role in soil restoration efforts. Techniques like soil remineralization, biochar application, and phytoremediation can help rehabilitate contaminated and degraded soils. These amendments can immobilize pollutants, enhance nutrient availability, and restore soil structure, allowing for the establishment of healthy vegetation (Munroe et al., 2015).

1.5. Wheat Farming and the Importance of It

Wheat, scientifically known as Triticum aestivum, is one of the most important cereal crops worldwide. It is cultivated extensively for its grains, which serve as a staple food source for a significant portion of the global population. Wheat production plays a crucial role in global food security and contributes to the livelihoods of millions of farmers. The cultivation of wheat involves various agricultural practices and management techniques to ensure optimal yield and quality. Understanding the importance of wheat and implementing sustainable production methods are vital for meeting the growing global demand for this essential crop.

1.5.1. Wheat Production

Wheat production involves several key aspects, including land preparation, seed selection, planting, crop management, and harvesting. It is primarily cultivated in temperate regions but can also be grown in some subtropical and tropical areas with specific varieties. Successful wheat production requires suitable soil conditions, adequate moisture, optimal temperature, and appropriate nutrient management. Farmers employ various techniques such as crop rotation, irrigation, pest control, and fertilization to maximize yield and minimize yield losses (CIMMYT, 2020).

1.5.2. The Importance of Wheat

Wheat holds immense importance for both human nutrition and the global economy. It is a rich source of carbohydrates, proteins, dietary fiber, and essential micronutrients, making it a valuable component of a balanced diet. Wheat-based products, including bread, pasta, and pastries, are consumed extensively worldwide, contributing to food culture and providing sustenance to millions of people. Moreover, wheat plays a significant role in national and international trade, contributing to economic growth and livelihoods of farmers, traders, and processors. (FAO, 2020; U.S. Wheat Associates, 2021).

Understanding the significance of wheat production and its role in addressing global food security and economic development is crucial for sustainable agricultural practices and future planning.

2. LITERATURE REVIEW

2.1. Importance of Soil Fertility and Crop Productivity

Soil fertility is a critical factor that significantly influences crop productivity and agricultural sustainability (Fageria et al., 2008). Adequate soil fertility is essential for providing plants with the necessary nutrients, water, and optimal physical environment for growth. Essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), iron (Fe), zinc (Zn), and manganese (Mn) are vital for plant growth and development (Fageria et al., 2008). Soil fertility directly impacts plant growth by providing accessible forms of nutrients, supporting photosynthesis, root development, and reproductive growth, and enhancing plant resistance to pests, diseases, and environmental stresses. Thus, maintaining proper soil fertility levels is crucial for achieving high crop yields and sustaining plant health (Lal, 2004).

Proper soil fertility management practices are essential for optimizing crop productivity. These practices include nutrient management, organic matter addition, pH adjustment, and irrigation management (Lal, 2004). Balanced fertilization, precision agriculture, and the use of organic amendments can replenish nutrient levels and maintain soil fertility, leading to increased crop production, improved yield stability, and better economic returns for farmers (Cavigelli et al., 2008). Conversely, nutrient deficiencies or imbalances can limit crop growth and result in reduced yields.

Implementing sustainable soil fertility management approaches is critical for long-term agricultural sustainability. Conservation tillage, crop rotation, cover cropping, and precision nutrient management are some of the sustainable practices that can enhance soil health, reduce nutrient losses, and improve ecosystem services (Drinkwater et al., 2010). These practices contribute to maintaining and enhancing soil fertility, supporting increased crop yields and overall agricultural sustainability.

In conclusion, soil fertility plays a crucial role in crop productivity. Adequate nutrient availability, proper soil fertility management practices, and the adoption of sustainable approaches are essential for maintaining soil fertility and achieving increased crop yields. Recognizing the significance of soil fertility and implementing appropriate management strategies are key to ensuring global food security and supporting sustainable agricultural systems (Lal, 2004).

2.2. Agricultural Byproducts as Potential Soil Amendments

Agricultural byproducts are gaining recognition as potential soil amendments due to their abundant availability and beneficial impact on soil properties. These byproducts, including crop residues, animal manures, and food processing wastes, can improve soil fertility, structure, and water-holding capacity. Research has shown that incorporating agricultural byproducts into the soil can enhance nutrient cycling, increase organic matter content, and promote microbial activity (Garcia-Gomez et al., 2018; Khattab et al., 2020). For instance, the addition of crop residues can increase soil organic carbon, enhance nutrient availability, and improve soil water retention (Jat et al., 2019). Animal manures, rich in organic matter and nutrients, contribute to soil fertility by providing essential elements for plant growth and improving soil structure (Sun et al., 2019). Food processing wastes, such as composted fruit and vegetable residues, can act as a source of organic matter and nutrients, enhancing soil fertility and promoting sustainable agriculture practices (Chen et al., 2020). Moreover, these byproducts can play a crucial role in reducing waste and environmental pollution while simultaneously benefiting soil health and crop productivity. Overall, utilizing agricultural byproducts as soil amendments offers a promising approach for sustainable soil management and agricultural practices.

2.3. Significance of Studying the Effect of Olive Pomace and Its Bottom Ash

Studying the effect of olive pomace and its bottom ash on soil and plant yield is significant for several reasons:

1. Soil Improvement: Olive pomace, which is the residue left after olive oil extraction, can be used as an organic amendment to improve soil quality. It contains organic matter, nutrients, and beneficial microorganisms that can enhance soil structure, fertility, and water-holding capacity. By studying its effect on soil, researchers can determine the optimal application rate and assess the potential benefits for soil health and productivity.

2. Nutrient Recycling: Olive pomace is rich in nutrients such as nitrogen, phosphorus, potassium, and organic matter. Recycling these nutrients back into the soil through the application of olive pomace and its bottom ash can reduce the need for synthetic fertilizers. Understanding the impact on nutrient availability and cycling in the soil is crucial for sustainable agriculture and minimizing environmental pollution caused by excess fertilizer use.

3. Plant Growth and Yield: The application of olive pomace and its bottom ash can influence plant growth, development, and yield. It provides essential nutrients to plants, promotes root development, and enhances nutrient uptake efficiency. Investigating the effects on different crops can help optimize application methods and rates to maximize crop productivity and quality.

4. Waste Management: Olive pomace and its bottom ash are by-products of olive oil production, and their disposal can pose environmental challenges. By studying their effects on soil and plant yield, researchers can identify sustainable ways to manage and utilize these waste materials, turning them into valuable resources. This reduces the environmental impact and promotes circular economy principles.

5. Soil Contaminant Remediation: In some cases, olive pomace and its bottom ash may contain certain contaminants, such as heavy metals or organic compounds. Studying their effect on soil and plant yield allows for the assessment of potential risks and the development of appropriate management practices to minimize any adverse impacts on soil and crop quality.

Overall, studying the effect of olive pomace and its bottom ash on soil and plant yield helps us better understand the potential benefits and risks associated with their application. This knowledge can contribute to sustainable agriculture practices, efficient waste management, and improved soil and crop productivity.

2.4. Olive Pomace: Composition and Characteristics

2.4.1. Description of Olive Pomace

Olive pomace refers to the residual material remaining after olive oil extraction, including the skins, pulp, and pits. It is considered a by-product of the olive oil industry and has gained attention for its potential applications in various fields. Olive pomace is rich in organic matter, nutrients, and bioactive compounds, making it a valuable resource for soil improvement and organic fertilizer production. It contains substantial amounts of nitrogen, phosphorus, potassium, and organic carbon, which can enhance soil fertility, structure, and water-holding capacity (J. Ojeda et al., 2017; F. R. Martins et al., 2021). The application of olive pomace has been shown to improve soil microbial activity, nutrient availability, and overall soil health (G. D'Agostino et al., 2021). Studies have demonstrated its positive impact on plant growth, root development, and crop yield, particularly in Mediterranean regions where olive cultivation is prevalent (M. Hachicha et al., 2019). Moreover, olive pomace offers a sustainable solution for waste management by recycling and repurposing the residues from olive oil production. However, it is important to consider the potential presence of contaminants in olive pomace, such as heavy metals and organic compounds, which may require careful assessment and appropriate management practices (J. Ojeda et al., 2017).

2.4.2. Chemical Composition and Nutrient Content

The chemical composition of olive pomace can vary depending on factors such as olive variety, processing methods, and climate conditions. On average, olive pomace contains about 40-60% moisture, 15-30% crude fiber, 5-15% crude protein, and 10-30% crude fat (A. A. Kefalas et al., 2003; S. Akkaya et al., 2013).

In terms of nutrient content, olive pomace is a good source of organic matter and contains several essential nutrients. It typically has nitrogen (N) content ranging from 1-4%, phosphorus (P) content of 0.2-0.6%, and potassium (K) content of 1-3% (M. Hachicha et al., 2019; F. R. Martins et al., 2021). Additionally, olive pomace contains varying amounts of other nutrients such as calcium (Ca), magnesium (Mg), sulfur (S), and trace elements like iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) (A. A. Kefalas et al., 2003; S. Akkaya et al., 2013).

Moreover, olive pomace is rich in phenolic compounds, which contribute to its antioxidant properties and potential health benefits (D. M. Yousfi et al., 2017; D. Selvam et al., 2021). These phenolic compounds include hydroxytyrosol, tyrosol, oleuropein, and other flavonoids, which have been studied for their anti-inflammatory, antimicrobial, and anticancer activities.

2.4.3. Physical Properties and Organic Matter Content

The physical properties of olive pomace can vary based on factors such as the olive variety, processing methods, and moisture content. Olive pomace typically has a bulk density ranging from 200 to 400 kg/m^3 and a particle size distribution that includes fine particles, coarse fragments, and varying degrees of fibrous material (C. I. Márquez-Molina et al., 2012; M. Hachicha et al., 2019).

Regarding organic matter content, olive pomace is known for its high organic matter content, which plays a crucial role in improving soil fertility and structure. The organic matter content of olive pomace can range from approximately 65% to 90% (S. Akkaya et al., 2013; F. R. Martins et al., 2021). It contributes to soil aggregation, water retention, and nutrient availability, promoting favorable conditions for plant growth.

2.4.4. Challenges and Limitations in Using Olive Pomace as a Soil Amendment

The utilization of olive pomace as a soil amendment is not without its challenges and limitations. One of the primary challenges is the potential presence of contaminants in olive pomace, including heavy metals and organic compounds. These contaminants may originate from various sources such as agrochemicals, soil pollution, or the olive oil production process itself. Their presence can pose risks to soil quality, plant health, and environmental sustainability (J. Ojeda et al., 2017). Additionally, the high moisture content of olive pomace can lead to increased microbial activity and potential odor issues during decomposition, necessitating proper management and application techniques to mitigate these concerns (F. R. Martins et al., 2021). The variability in chemical composition and nutrient content of olive pomace can also pose challenges in terms of determining optimal application rates and achieving consistent results across different soil types and agricultural systems (M. Hachicha et al., 2019). Furthermore, the bulkiness and low density of olive pomace may limit its transport, storage, and application feasibility, particularly in large-scale agricultural operations (A. A. Kefalas et al., 2003). Despite these challenges, through proper evaluation, careful management, and adherence to regulations and guidelines, the use of olive pomace as a soil amendment can still offer significant benefits for soil fertility, organic matter enrichment, and sustainable agriculture practices (S. Akkaya et al., 2013).

2.5. Olive Pomace Bottom Ash: Production and Properties

2.5.1. Production Process and Characteristics of Olive Pomace Bottom Ash

Olive pomace bottom ash is a by-product generated from the incineration of olive pomace, which is the residue remaining after olive oil extraction. The production process involves the combustion of olive pomace under controlled conditions, resulting in the formation of ash. Olive pomace bottom ash is characterized by its fine particle size and typically has a grayish or black color. It contains various elements, including calcium, potassium, phosphorus, and trace elements such as iron, manganese, and zinc. The chemical composition of olive pomace bottom ash can vary depending on factors such as the olive variety, combustion conditions, and pre-treatment methods. The ash is known to have alkaline properties, contributing to its potential as a soil amendment for pH adjustment and nutrient supplementation. It also has the potential to improve soil structure, water retention capacity, and nutrient availability, thereby enhancing plant growth and yield (M. Hachicha et al., 2019; D. M. Yousfi et al., 2019). Furthermore, the use of olive pomace bottom ash as a soil amendment can offer a sustainable solution for the disposal and utilization of olive oil industry by-products (D. M. Yousfi et al., 2017).

2.5.2. Chemical Composition and Nutrient Content

Olive pomace bottom ash, derived from the combustion of olive pomace, exhibits a distinctive chemical composition and nutrient content. The ash composition can vary depending on factors such as the olive variety, combustion conditions, and pre-treatment methods. Generally, olive pomace bottom ash is characterized by its high mineral content, including calcium (Ca), potassium (K), phosphorus (P), and trace elements such as iron (Fe), manganese (Mn), and zinc (Zn). These elements contribute to the potential benefits of olive pomace bottom ash as a soil amendment. The ash can help in adjusting soil pH, improving nutrient availability, and enhancing soil fertility. Additionally, the presence of these nutrients in the ash can promote plant growth, root development, and overall crop yield (M. Hachicha et al., 2019; D. M. Yousfi et al., 2019; Y. Mekki et al., 2020). The utilization of olive pomace bottom ash as a soil amendment provides a sustainable approach to recycle and repurpose the by-products of the olive oil industry, offering both environmental and agronomic benefits.

2.5.3. Physical Properties and Potential Benefits as a Soil Amendment

Olive pomace bottom ash, generated from the incineration of olive pomace, possesses unique physical properties that make it suitable as a soil amendment. The ash typically has a fine particle size, which aids in its incorporation into the soil and distribution of nutrients. It also exhibits alkaline properties, contributing to pH adjustment in acidic soils. Olive pomace bottom ash has the potential to improve soil structure and porosity, thereby enhancing water infiltration and retention. Its high mineral content, including calcium (Ca), potassium (K), and phosphorus (P), provides essential nutrients for plant growth and development. Additionally, the ash's ability to release these nutrients slowly over time can contribute to sustained nutrient availability. Furthermore, the incorporation of olive pomace bottom ash into the soil can enhance organic matter content and promote microbial activity, leading to improved soil fertility and nutrient cycling. These attributes make olive pomace bottom ash a promising soil amendment for agricultural practices, aiding in sustainable crop production and soil health improvement (M. Hachicha et al., 2019; Y. Mekki et al., 2020).

2.5.4. Considerations for Proper Utilization and Application of Olive Pomace Bottom Ash

Proper utilization and application of olive pomace bottom ash as a soil amendment require careful consideration of several factors. Firstly, the application rate should be determined based on soil characteristics, crop requirements, and nutrient content of the ash to avoid over- or under-application. It is essential to conduct soil testing and nutrient analysis to assess the nutrient needs of the target crops accurately. Secondly, the timing and method of application are crucial. Incorporating the ash into the soil during land preparation or as a top dressing should be done at appropriate stages of crop growth to maximize nutrient availability and minimize nutrient losses. Additionally, considerations should be given to the potential release of alkaline compounds from the ash, which may affect soil pH. Monitoring and managing the pH levels, especially in acid-sensitive crops or acidic soils, are important for maintaining optimal growing conditions. Lastly, adherence to regulatory guidelines and local regulations regarding the use of olive pomace bottom ash is essential to ensure environmental sustainability and compliance with standards (M. Hachicha et al., 2019; Y. Mekki et al., 2020).

2.6. Effects of Olive Pomace on Clay Soil

Several studies have examined the effects of olive pomace on clay soils, providing valuable insights into its potential benefits. Tognetti et al. (2012) conducted research on a clay soil in Italy and found that the application of olive pomace increased soil organic matter content, leading to improved soil structure and increased aggregate stability. In a study by García-Delgado et al. (2014) conducted in Spain, different rates of olive pomace application were assessed on a clay soil, revealing enhanced soil fertility through increased nutrient availability and improved water holding capacity. The organic matter in olive pomace also stimulated microbial activity in the soil, thereby contributing to nutrient cycling and overall soil health. These studies demonstrate the potential of olive pomace as an organic amendment to enhance clay soil properties, although specific effects may vary based on soil type, climate, and application rates.

2.7. Effects of Olive Pomace on Sandy Soil

The application of olive pomace, the byproduct of olive oil production, has been investigated for its impact on sandy soils. Research studies provide insights into the potential benefits of olive pomace in improving soil properties. For instance, a study by Teixeira et al. (2017) examined the effects of olive pomace application on sandy soil in Portugal. The results revealed that olive pomace significantly increased soil organic matter content and improved soil structure by enhancing aggregate stability. Another study by Hachicha et al. (2010) conducted in Tunisia demonstrated that the incorporation of olive pomace into sandy soil increased soil water retention capacity and improved soil fertility through the slow release of nutrients during decomposition. These findings highlight the positive influence of olive pomace as an organic amendment on sandy soil properties, including enhanced organic matter content, improved soil structure, and increased water retention capacity.

2.8. Effects of Olive Pomace and Olive Pomace Bottom Ash on Wheat Yield

The impact of olive pomace and olive pomace bottom ash on wheat yield has been investigated in research studies. For instance, a study by Traversa et al. (2015) examined the effects of olive pomace and olive pomace bottom ash application on wheat cultivation in Italy. The results indicated that both olive pomace and olive pomace bottom ash positively influenced wheat yield, with significant increases observed compared to control treatments. The addition of olive pomace and olive pomace bottom ash improved soil fertility, enhanced nutrient availability, and positively affected soil structure, leading to improved wheat growth and yield. Another study by Paradelo et al. (2016) investigated the effects of olive pomace bottom ash on wheat yield in Spain. The results demonstrated that the application of olive pomace bottom ash resulted in a significant increase in wheat yield, attributed to improved soil nutrient content and reduced nutrient losses. These findings highlight the potential of both olive pomace and olive pomace bottom ash as beneficial amendments for enhancing wheat yield.

2.9. Future Directions and Research Gaps

The research on the effects of olive pomace and olive pomace bottom ash on soil and crop yield has provided valuable insights. However, there are still some future directions and research gaps that warrant further investigation. Here are a few areas for future research:

1. Optimization of Application Rates: More studies are needed to determine the optimal application rates of olive pomace and olive pomace bottom ash for different soil types, crop species, and environmental conditions. Understanding the appropriate dosage is crucial to maximize the benefits while avoiding any potential negative effects.

2. Long-Term Effects: Most existing studies focus on short-term effects, and there is a need for long-term investigations to assess the sustainability and persistence of the benefits provided by olive pomace and olive pomace bottom ash. Longitudinal studies would shed light on the potential accumulation of nutrients or contaminants in the soil over time.

3. Nutrient Release Dynamics: Further research is required to understand the release dynamics of nutrients from olive pomace and olive pomace bottom ash. Examining the timing and rates of nutrient release would help optimize nutrient availability to crops and minimize nutrient losses through leaching or runoff.

4. Crop-Specific Responses: Different crops may respond differently to the application of olive pomace and olive pomace bottom ash. Future research should explore the specific effects on various crop species and investigate crop-specific nutrient requirements, growth responses, and potential changes in crop quality attributes.

5. Environmental Impacts: While olive pomace and olive pomace bottom ash offer potential benefits, there is a need to investigate their potential environmental impacts. Studies should evaluate the effects on soil microbial communities, greenhouse gas emissions, and potential leaching or runoff of contaminants to ensure sustainable agricultural practices.

By addressing these future directions and research gaps, scientists can continue to deepen their understanding of the effects of olive pomace and olive pomace bottom ash on soil and crop yield, leading to improved agricultural practices and sustainable resource utilization.

3. MATERIALS AND METHODS

3.1. Description of the Soil Sampling Area

Two types of soil were used for the experiment, Clay soil and Sandy Loam soil.

As for the clay soil it was collected from the agriculture field at Ondokuz Mayis University in Samsun, Turkey. The mean annual maximum and minimum temperature are 5°c to 27.7°c. The average annual precipitation is 937.26 mm per year. The soil was observed to be dark brown to black and is classified as clay soil.

As for the sandy loam soil, it was collected from the experimental station of agricultural faculty in Bafra plain, Samsun, Turkey. Affiliated to Ondokuz Mayis University. The mean annual maximum and minimum temperature are 6.6°c to 23°c. The average annual precipitation is 670.4 mm per year. The soil was observed to be light brown and is classified as sandy loam soil.

3.2. Pre-treated Soil Physical and Chemical Analysis

Physiochemical analysis of the two soils used in the experiment was carried out in order to compare the results with treated soils. About 100g of soil was collected as a sample to conduct a pre-treatment analysis. For each test, three replicates were made to reduce variability in experimental results. The results of the analysis are listed below in table 3.1.

Table 3.1. Pre-treated soil physical and chemical Analysis.

Soil Properties	Clay Soil	Sandy Loam Soil
pH	6.58	6.32
EC (μs/cm)	451.5	563
Moisture Content	1.7%	0.6%
Soil Texture (By using Bouyoucos Hydrometer)	Clay Soil	Sandy Loam Soil
Soil Organic Matter	2.7%	4.8%
Lime ($CaCO_3$) content (calcimeter method)	2.3%	15.6%
Exchangeable Ca (meq/100g)	40.96	33.5
Exchangeable Mg (meq/100g)	12.68	14.85
Phosphorus Content (Olsen method) (ppm)	30	109

3.3. Olive Pomace Production and its Properties

The olive pomace used in this study was obtained from olive mill located in Turkey, after the olive oil production process (pressing or centrifugation). This residue is treated with solvents to extract the oil it contains to obtain crude olive pomace oil. The properties of the olive pomace used in the study are listed below in table 3.2.

Table 3.2. Properties of the olive pomace used in the study.

Parameters	Results
pH	6.07
EC (µs/cm)	3796
Moisture Content	2%
Moisture Content at Field Capacity	58%
Moisture Content at Permanent Welting Point	50%
Plant Available Water	8%

Figure 3.1. Olive pomace used in the experiment.

3.4. Olive Pomace Bottom Ash Production and its Properties

The olive pomace bottom ash used in this study was generated from the incineration of olive pomace at 560°c for one night using a laboratory incinerator. The properties of the olive pomace bottom ash used in the study are listed below in table 3.3.

Figure 3.2. Incineration process of OP to produce OPBA.

Table 3.3. Properties of the olive pomace bottom ash used in the study.

Parameters	Results
pH	10.08
EC (mS/cm)	57.14
Moisture Content at Field Capacity	48%
Moisture Content at Permanent Welting Point	36%
Plant Available Water	12%
Fe (ppm)	469
Cu (ppm)	9.98
Zn (ppm)	16.98
Mn (ppm)	12.08
Ca (ppm)	3432.38
Mg (ppm)	668.79
K (ppm)	18074.6

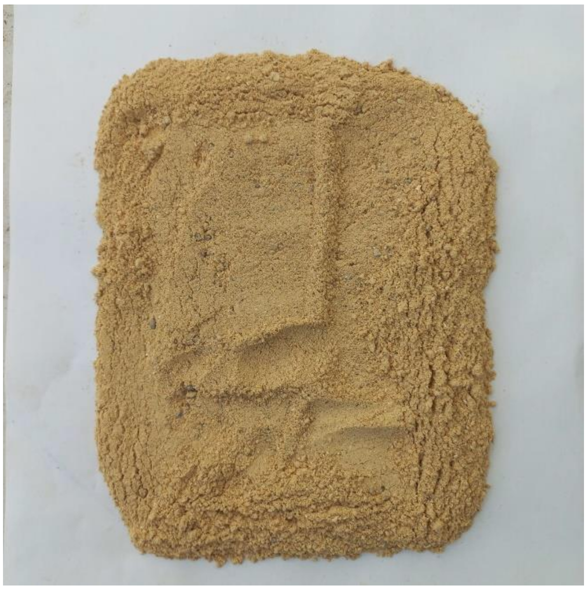

Figure 3.3. Olive pomace bottom ash used in the experiment.

3.5. Description of the Indicator Plant Used

Wheat variety ‘Altindane’ was used as an indicator plant. Altindane is a cultivar with awn, white spike, white kernel and medium early maturing. The Spike leans down during maturity. It can grow up 80-100 cm in optimum conditions. Threshing character is good. Resistant to shattering. It shows a good response to nitrogen fertilization and irrigation. The grain yield is changing 400-1150 kg/da in different conditions.

Altindane is resistant to rusts (stripe, leaf and stem rust), powdery mildew and lodging. It is midd-susceptible to winter damage and sprouting. Altindane was developed and registered by Black Sea Agricultural Research Institute in 2012. It can be recommended to spring sowing conditions. The properties of the “Altindane” wheat variety are listed below in table 3.4.

Table 3.4. Properties of the “Altindane” wheat variety.

Wheat Properties	Results
Hectoliter (kg)	80-82
1000 kernel (g)	32-45
Gluten index	98-99
Energy	140-430
Protein rate	13-18
SDS sedimentation (ml)	48-68
Flour yield	66%

3.6. Green-House Experiment

The experiment was conducted in controlled environmental conditions where the temperature was maintained. Rain-water was used to irrigate plants. Soil moisture content was maintained into two levels 100% of the soil field capacity, and 30% of the plant available water),to study the response to water stress. The moisture content was maintained under the two levels by weighing the pots every two days to determine the moisture depletion and replenishing the moisture content into the two irrigation levels.

3.6.1. Description of Experiment

A total of 48 pots were utilized in the experiments, with three replicates of each treatment (including six pots used as control). About 100kg of soil (50kg clay soil and 50kg sandy loam soil) was collected and placed in the faculty of agriculture soil room on a clean surface for 15-20 days to allow it to dry naturally. It was then crushed with a wooden hammer and manually sieved through a 4mm sieve, for preparing homogenized soil conditions for each treatment. Each pot was filled with 2kg (oven dry weight) of soil.

Olive Pomace treatment was applied in 2% (percentage weight by weight w/w of soil), Olive Pomace Bottom Ash treatment was applied in 0.1% (percentage weight by weight w/w of soil), and a mixture of Olive Pomace and Olive Pomace Bottom Ash treatment was applied in 1% Olive Pomace + 0.05% Olive Pomace Bottom Ash (percentage weight by weight w/w of soil).

Seed rate of the wheat used in the experiment was calculated according to soil area on top of the pot using the standard wheat seed rate 550 seeds/m^2.

Figure 3.4. Pots used in the experiment after application.

3.6.2. Experimental Design and Data Collection

A three factors factorial design (soil type, application type, and irrigation level) was set. A total of 16 treatments were decided including control, in which each olive pomace, olive pomace bottom ash, the mixture of both, and two irrigation levels was decided to be applied as shown in table 3.5.

Table 3.5. Description of the experimental design.

Treatment no	Soil type	Irrigation	Treatment	Dose (%w/w)	Abbreviation
1	Clay	100%	Control	Null	C1C
2	Clay	100%	Pomace	2%	C1P
3	Clay	100%	Ash	0.1%	C1A
4	Clay	100%	Mix	1% + 0.05%	C1M
5	Clay	30%	Control	Null	C3C
6	Clay	30%	Pomace	2%	C3P
7	Clay	30%	Ash	0.1%	C3A
8	Clay	30%	Mix	1% + 0.05%	C3M
9	Sandy loam	100%	Control	Null	B1C
10	Sandy loam	100%	Pomace	2%	B1P
11	Sandy loam	100%	Ash	0.1%	B1A
12	Sandy loam	100%	Mix	1% + 0.05%	B1M
13	Sandy loam	30%	Control	Null	B3C
14	Sandy loam	30%	Pomace	2%	B3P
15	Sandy loam	30%	Ash	0.1%	B3A
16	Sandy loam	30%	Mix	1% + 0.05%	B3M

Data collection for the green house phase was divided into two periods.

3.6.2.1. Plant Growth Stage

During the plant growth stage data of each plant was collected which included:

1. Weight of pots (g)

In the initial stages of the experiment, field capacity and plant available water of the two soils was calculated and the final weights (after irrigation) of the pots were determined that was to be used as a reference to irrigate the plants every two days, so that pots was not over or under irrigated according to two levels of irrigation.

2. Germination percentage (GP). (ISTA, 1996).

$$GP = \frac{\text{Number of normally germinated seeds}}{\text{Total number of seeds}} \times 100$$

3. Evapotranspiration (ml)

During the experimental period, the loss of water in the pots as a result of evapotranspiration was determined by comparing the weight of the pot right before irrigation with its final weight after irrigation.

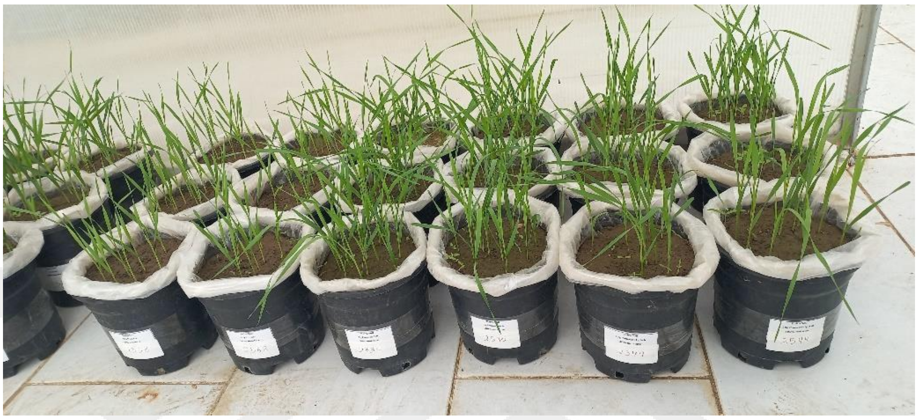

Figure 3.5. Plant growth stage.

3.6.2.2. Maturation Stage

After the end of 5 months and 20 days, each plant was harvested by clipping the shoot at soil level. After harvesting the mature plants, agronomical factors of plants were collected, that included:

1. Number of plants per pot
2. Plant biomass:

   Taking the difference between the weight of pot with plants and the weight of pot after harvesting.
3. Height of each plant:

   Taking the length of the plant using a ruler from the beginning of the plant stem at the bottom until the end of the highest awn at the top of the plat spike.

Figure 3.6. Measuring plant height.

4. Height of each plant spike:

Taking the length of the plant spike using a ruler from the beginning of the spike at the bottom until the end of the highest awn at the top of the spike.

Figure 3.7. Measuring spike length.

5. Diameter of each plant:

Taking the diameter of the plant from the stem using a digital caliper.

Figure 3.8. Measuring plant diameter.

6. Number of grains per spike
7. Weight of grains per spike
8. Weight of grains per pot
9. Weight of 1000 grain


Figure 3.9. Plant maturation stage.

3.6.2.3. Undisturbed Soil Analysis (post-harvesting)

After collecting the plant agronomical factors, soil characteristics that needs the soil to be undisturbed were measured that included:

1. Soil dry bulk density

Taking the depth of the soil surface using a ruler according to the top of the pot to measure the soil height by abstracting the depth from the total pot height, and the diameter of the soil surface and the soil bottom using a ruler since that the used pots in the experiment are conical in shape.

Figure 3.10. Measuring the depth of soil surface.

After that calculating the soil volume using the formula:

$$V = \frac{\pi}{3} h \left(r_1^2 + r_2^2 + r_1 \times r_2\right)$$

Where:

V: volume of the conical shape

h: height of the soil

r_1: radius of the soil surface

r_2: radius of the soil bottom

After calculating the soil volume and measuring the soil dry mass in the pot, calculate the soil dry bulk density using the formula:

$$\rho_b = \frac{M_s}{v_t}$$

Where:

P_b: soil dry bulk density

Ms: soil dry mass (solid mass)

Vt: soil total volume

2. Soil Porosity

After calculating the soil dry bulk density, use its value to calculate the soil porosity using the formula:

$$\phi = 1 - \frac{\rho_b}{\rho_d}$$

Where:

Φ: soil porosity

P_b: soil dry bulk density

P_d: soil particle density

3. Soil penetration resistance

Taking the soil penetration resistance reading using a digital pocket penetration resistance device.

Figure 3.11. Measuring soil penetration resistance in process.

4. Harvest index

After harvesting the plant, the plant biomass (biological yield) and grain yield (economic yield) were measured, using both values the harvest index was calculated using the following equation according to (Beadle, 1985).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

5. Water use efficiency

After harvesting the plant water consumption (mm) in the total plant growth stage and plant yield (g) were measured, using both values the water use efficiency was calculated using the following equation according to (Howell et al., 1990).

$$WUE = \frac{\mathrm{Y}}{\mathrm{ET}}$$

Where:

Y: Plant yield under irrigated conditions

ET: Plant water consumption

3.7. Disturbed Soil Factors (laboratory analysis)

After harvesting the plants, and collect the undisturbed soil measurements, soil samples were collected from each pot and air-dried for 10 days to use in soil physiochemical analysis.

Figure 3.12. Air- drying the soil to prepare for lab analysis.

3.7.1. Post-treatment Soil Chemical Analysis

Following is the list of chemical analyses that were carried out for each pot to generate data for observation:

1. pH and EC values were measured in 1:1 (w/v) soil : water suspension with pH and EC meter (Bayrakli, 1987).

2. Soil organic matter were calculated as stated in (Nelson and Sommers, 1982) using the organic carbon value in the soil determined by the "Walkley-Black" wet oxidation method.

3. Available phosphorus content determined according to Olsen Method (Kacar and Unal, 2008).

4. Exchangeable cations such as potassium (K), sodium (Na), calcium (Ca) and magnesium (Mg) were determined in the soil suspension filtrate obtained with 1.0 N neutral ammonium acetate solution of the soil sample (Kacar, 1994). The amount of K and Na in the filtrate was determined by Atomic Absorption Spectrophotometer (AAS), and the exchangeable Ca and Mg amounts were determined by titration with EDTA (Kacar, 1994).

5. Lime content (CaCO3) in the soil was determined based on the volume of carbon dioxide gas released as a result of the disintegration of calcium carbonate from the soil treated with 1/3 HCl by Scheibler calcimeter under standard temperature and pressure (Allison and Moodie, 1965).

6. Cation exchange capacity of the soil was determined by replacing Ammonium in Ammonium Acetate solution (Kacar, 1994).

Figure 3.13. Chemical analysis in process.

3.7.2. Post-treatment Soil Physical Analysis

Following is the list of physical analysis that were carried out for each pot to generate data for observation:

1. Aggregate stability (AS) values of soil samples were determined by "wet sieving" method using a "Yoder" type wet sieving device, soaked from the bottom in the solution for 5 minutes and sieved in this solution for 5 minutes. At the end of the sieving process, the aggregate stability (AS) values are expressed as percentages after sand corrections are calculated with the following equation (Demiralay, 1993).

$$AS\% = \frac{(\text{Oven dry stable aggregates} - \text{Sand}) \times 100}{(\text{Oven} - \text{dry soil weight Sand})}$$

Figure 3.14. Aggregate stability test in process.

2. Structure Stability index (SSI) for the soil samples was determined based on hydrometer measurements and using the following equation (Lal and Elliot, 1994).

$$SSI = \sum n - \sum b$$

Where:

$\sum$n: the sum of silt (%) and clay (%) fractions obtained by mechanical analysis,

$\sum$b: the sum of silt (%) and clay (%) fractions dispersed from aggregates (%) to suspension.

3. Dispersion ratio (DR) for the soil samples was determined based on hydrometer measurements and using the following equation (Lal and Elliot, 1994).

$$DR = \frac{\sum b}{\sum n} \times 100$$

Where:

$\sum$b: the sum of silt (%) and clay (%) fractions dispersed from aggregates (%) to suspension.

$\sum$n: the sum of silt (%) and clay (%) fractions obtained by mechanical analysis,

4. Crust formation (CF) of the soil samples was determined using the following equation according to (Pieri, 1989).

$$CF = \frac{OM\% \times 100}{C\% + Si\%}$$

Where:

OM%: soil organic matter percentage

C%: Clay percentage in the soil

Si%: Silt percentage in the soil

The value obtained in terms of crust formation indicates very severe physical degradation in the soils if it is less than 5, severe physical degradation between 5 and 7, low physical degradation between 7 and 9, and no physical degradation if it is greater than 9.

5. Moisture content at field capacity for the soil samples was measured using pressure plate apparatus which remove the soil moisture under controlled condition, for field capacity stage a 0.33 bar pressure is used, then the soil samples are weighed and moved into the oven for one night at 105℃ to measure the soil sample oven-dry weight, then calculating the moisture content at field capacity using the following equation:

$$w = \mathrm{Mw}/\mathrm{Ms}$$

Where:

w: Gravimetric water content

Mw: Mass of water in the soil sample (wet soil – dry soil)

Ms: Mass of dry soil

6. Moisture content at permanent wilting point for the soil samples was measured using pressure plate apparatus which remove the soil moisture under controlled condition, for permanent wilting point stage a 15 bar pressure is used, then the soil samples are weighed and moved into the oven for one night at 105℃ to measure the soil sample oven-dry weight, then calculating the moisture content at permanent wilting point using the following equation:

$$w = \mathrm{Mw}/\mathrm{Ms}$$

Where:

w: Soil gravimetric water content

Mw: Mass of water in the soil sample (wet soil – dry soil)

Ms: Mass of dry soil

7. Available water for plant (AWP) in soil samples was measured using the equation:

$$AWP = \mathrm{FC} - \mathrm{PWP}$$

Where:

FC: Soil moisture content at field capacity

PWP: Soil moisture content at permanent wilting point

Figure 3.15. Pressure plate apparatus preparation.

The outcomes of this experiment were statistically evaluated using JMP Pro 14 program in a three factors factorial design. The means of results were compared using a Duncan test at 0.01 and 0.05 levels and F values of significant application were given with ** at 0.01 and * at 0.05 levels.

4. RESULTS AND DISCUSSION

4.1. The Effect of Treatments on Plant Yield and Properties

4.1.1. Plant Biomass

The treatments of different applications affected the plant biomass significantly ($p<0.01$) according to the three factors interaction.

The lowest plant biomass was observed with OP application in clay soil with 30% irrigation, which could be attributed to the limited nutrient availability and reduced water-holding capacity of clay soil.

Similarly, OP application in sandy loam soil with 100% irrigation yielded the lowest biomass, potentially due to the increased risk of nutrient leaching and waterlogging in sandy loam soil under high irrigation.

Surprisingly, OP application in sandy loam soil with 30% irrigation resulted in higher biomass compared to sandy loam soil with 100% irrigation, possibly indicating a more favorable nutrient retention and reduced water stress with lower irrigation levels.

In contrast, OPBA application in sandy loam soil showed consistent biomass values for both 30% and 100% irrigation levels, suggesting that OPBA application alone might have minimal impact on plant biomass in sandy loam soil. However, in clay soil, OPBA application with 30% irrigation slightly increased biomass, potentially due to the addition of beneficial nutrients and improved soil structure.

Notably, OPBA application in clay soil with 100% irrigation significantly increased biomass compared to the control, indicating the combined positive effects of OPBA application and sufficient irrigation on nutrient availability and water retention in clay soil.

OP+OPBA application resulted in lower biomass than the control but higher biomass than OP application in both soil types and irrigation percentages, likely due to the varying nutrient compositions and interactions among the substances in the OP+OPBA. These results highlight the importance of considering soil type, irrigation percentage, and application type in optimizing plant growth, as factors such as nutrient availability, water retention, and soil characteristics play key roles in determining plant biomass under different conditions.

In a study conducted by Assaf et al. (2009) on chickpea (Cicer arietinum L.) under field conditions, it was found that OP amended soils increased plant biomass. The effect of treatments on plant biomass is given in Fig 4.1.

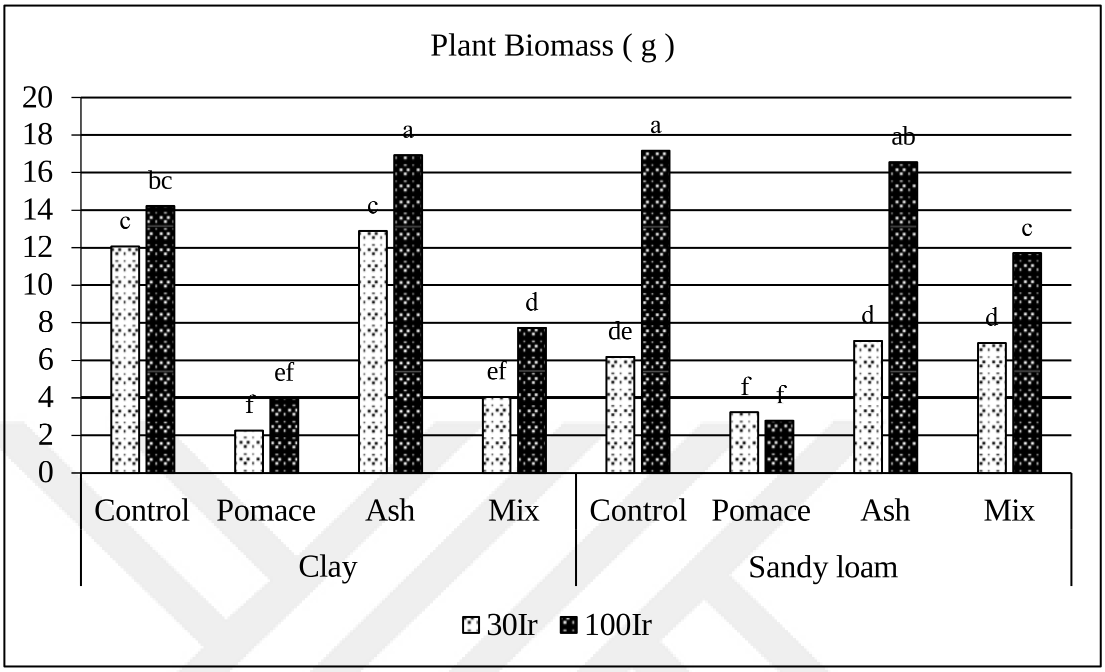

Figure 4.1. The effect of treatments on the plant biomass.

4.1.2. Plant Height

Interestingly, the three factors interaction do not appear to significantly impact plant height. However, other factors, such as the application type and its interaction with soil type, do influence plant height.

Specifically, the application of OPBA in clay soil increases plant height in both irrigation percentages compared to the control. This suggests that OPBA application provides beneficial nutrients or enhances soil structure, leading to improved plant growth and increased height. On the other hand, OP application in clay soil decreases plant height in both irrigation percentages compared to the control. This could be attributed to potential negative effects of OP on plant growth or nutrient availability in clay soil.

Furthermore, OP+OPBA application results in plant height lower than the control but higher than OP application in both irrigation percentages. This indicates that the OP+OPBA application may have a moderated effect on plant growth, likely due to a combination of different substances and their interactions.

Similar patterns are observed in sandy loam soil. The application of OPBA in sandy loam soil, with both irrigation percentages, results in higher plant height compared to the control in sandy loam soil. However, the plant height with OPBA application in sandy loam soil remains lower than the OPBA application in clay soil. This difference could be attributed to the variations in soil properties and nutrient retention capacity between sandy loam and clay soils.

İn a study conducted by Alma & Söylemez (2022) on pepper seedling (Capsicum Annuum), it was found that mixing 5% OP into the growing medium reduced plant height by approximately 16%hwile mixing 20% OP reduced plant height by approximately 59% compared to the control. Also Killi & kavdir (2013) confirmed that the addition of OP to the soil induced a significant reduction in plant height. While Assaf et al. (2009) observed that OP application to soil increased the plant height.

In summary, the findings indicate that irrigation percentages do not significantly affect plant height in this experiment. Instead, the interaction between the application type and soil type plays a prominent role. OPBA application generally promotes plant height in both soil types, while OP application tends to decrease plant height. The OP+OPBA application falls in between these two extremes. These results highlight the importance of considering application types and their interactions with soil types when aiming to influence plant height. The effect of treatments on plant height is given in Fig 4.2.

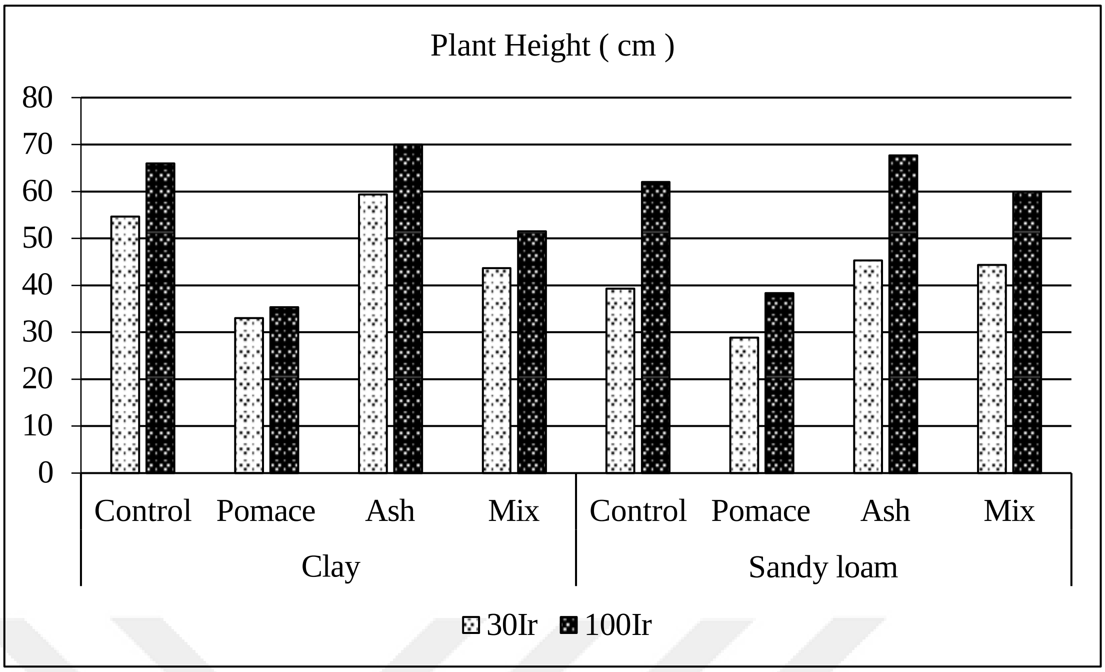

Figure 4.2. The effect of treatments on the plant height.

4.1.3. Spike Length

The three factors interaction have no significant effect on the spike length. Even though, the different applications have effect on the spike length.

In clay soil, the irrigation percentage does not appear to significantly impact spike length. However, OP application in clay soil leads to a decrease in spike length in both irrigation percentages. This suggests that the presence of OP negatively affects the development or elongation of spikes in clay soil.

Interestingly, the application of OPBA in clay soil with 100% irrigation slightly increases spike length compared to the control. This indicates that OPBA application may contribute to spike elongation in clay soil, possibly through the provision of essential nutrients or beneficial effects on soil structure. Moreover, the application of OPBA in clay soil with 30% irrigation results in increased spike length compared to both 100% irrigation and the control. This could be attributed to the moderation of irrigation levels, which might optimize nutrient availability and water balance for spike development.

Regarding the OP+OPBA application in clay soil, spike length is higher with 100% irrigation compared to 30% irrigation. However, both conditions still yield spike lengths lower than the control and OPBA application. This suggests that the

OP+OPBA application influences spike development to a lesser extent than OPBA application, but more than OP application in clay soil.

Moving to sandy loam soil, the control of sandy loam soil with 100% irrigation has a higher spike length compared to the control with 30% irrigation. Both controls exhibit higher spike lengths than the control of clay soil. The application of OPBA in sandy loam soil does not appear to have a significant effect on spike length compared to the control in sandy loam soil.

In terms of OP+OPBA application in sandy loam soil, the spike length is higher with 100% irrigation compared to 30% irrigation. Both conditions yield spike lengths higher than the OP+OPBA application in clay soil but lower than OPBA application in sandy loam soil. This suggests that the OP+OPBA application in sandy loam soil promotes spike development to a greater extent than in clay soil but falls short of the benefits observed with OPBA application.

In summary, the results indicate that the irrigation percentage in clay soil does not significantly impact spike length. OP application tends to decrease spike length, while OPBA application, especially with 100% irrigation, may enhance spike development in clay soil. OP+OPBA application falls in between these extremes. In sandy loam soil, the control exhibits higher spike length with 100% irrigation compared to 30% irrigation. The effects of OPBA application and OP+OPBA application on spike length in sandy loam soil are relatively minor. These findings highlight the role of soil type and application type in influencing spike length and emphasize the importance of considering these factors when aiming to optimize spike development. The effect of treatments on spike length is given in Fig 4.3.

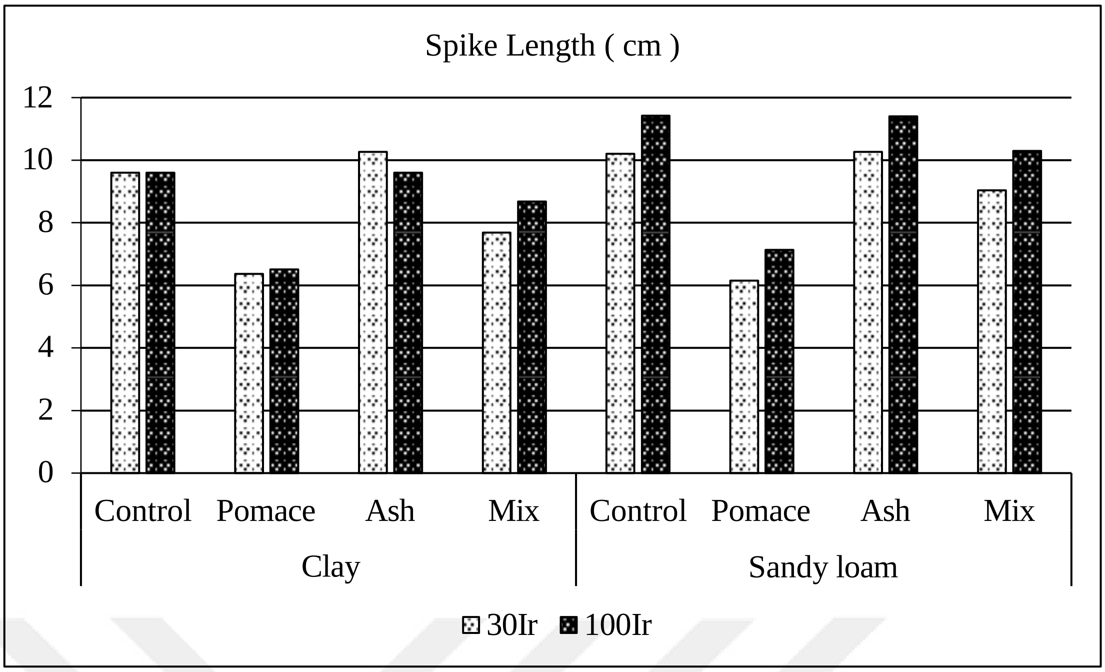

Figure 4.3. The effect of treatments on the spike length.

4.1.4. Plant Diameter

The three factors interaction significantly ($p<0.01$) affected the plant diameter.

In clay soil, there are small differences in plant diameter when comparing the irrigation percentages. However, in sandy loam soil, there is a significant difference in plant diameter according to the irrigation percentages.

Regarding OP application in clay soil, it leads to a decrease in plant diameter compared to the control, regardless of the irrigation percentages. This suggests that the presence of OP negatively affects plant growth and leads to a reduction in plant diameter in clay soil.

In contrast, OPBA application in clay soil with both irrigation percentages yields nearly the same results as the control, indicating that OPBA application does not significantly impact plant diameter in clay soil.

For OP+OPBA application in clay soil with both irrigation percentages, the plant diameter is slightly higher than with OP application but lower than with OPBA and the control. This suggests that the OP+OPBA application has a moderate effect on plant diameter in clay soil.

Moving to sandy loam soil, plant diameter in 100% irrigation appears to be higher than in 30% irrigation across all applications. This indicates that higher irrigation levels contribute to increased plant diameter in sandy loam soil.

The OP application in sandy loam soil results in the lowest plant diameter, suggesting that OP negatively affects plant growth and leads to reduced plant diameter in sandy loam soil.

OPBA application in sandy loam soil with 100% irrigation yields the highest plant diameter, while with 30% irrigation, it remains the same as the control. This indicates that OPBA application, particularly with higher irrigation levels, promotes plant growth and increases plant diameter in sandy loam soil.

The OP+OPBA application in sandy loam soil falls between the effects of OPBA and OP applications, with plant diameter lower than OPBA application but higher than OP application.

According to a study conducted by Alma & Söylemez (2022) on pepper seedling (Capsicum Annuum), Adding 5% OP to the growing medium decreased the stem diameter by 23.05%, while increasing the pomace rate to 20% caused a 48.91% decrease in stem diameter compared to the control.

In summary, the results show that in clay soil, irrigation percentages have a minimal impact on plant diameter. OP application decreases plant diameter, OPBA application has little effect, and OP+OPBA application yields intermediate results. However, in sandy loam soil, higher irrigation levels are associated with increased plant diameter. OP application results in the lowest diameter, while OPBA application, especially with 100% irrigation, leads to the highest diameter. The mix application falls between these extremes. These findings highlight the importance of considering irrigation levels and application types when aiming to optimize plant diameter, as they influence plant growth and development in both clay and sandy loam soils. The effect of treatments on plant diameter is given in Fig 4.4.

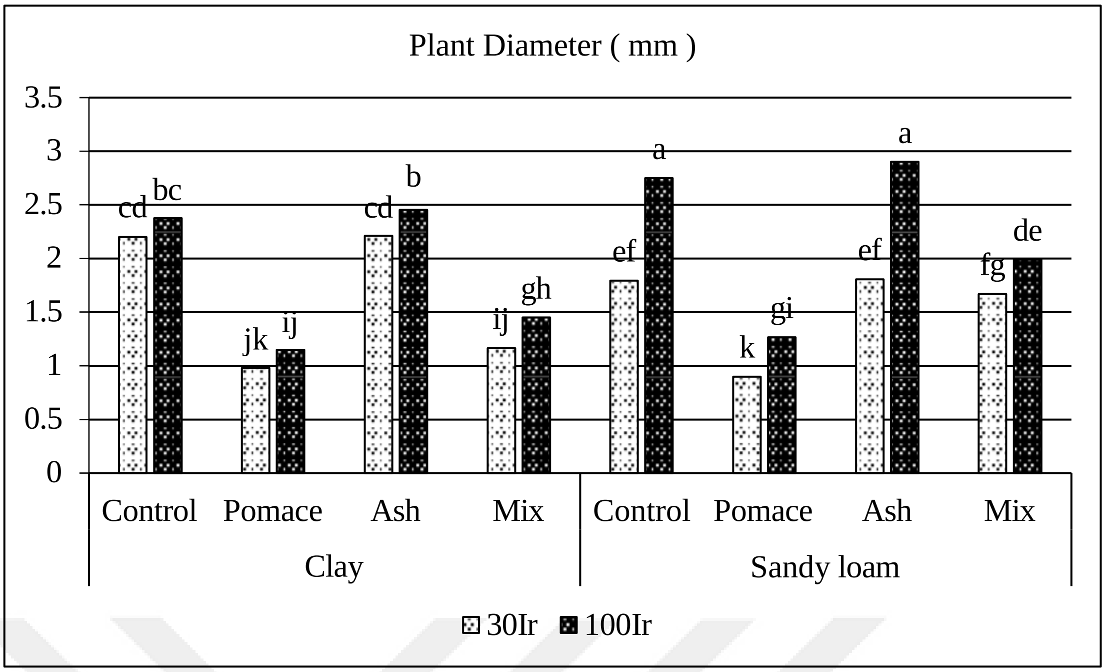

Figure 4.4. The effect of treatments on the plant diameter.

4.1.5. Number of Grains per Spike

The three factors interaction significantly ($p<0.01$) affected the number of grains per spike.

Regarding the irrigation percentage, both clay soil and sandy loam soil show higher results in the number of grains per spike with 100% irrigation compared to lower percentages.

In clay soil, the application of OP, compared to the control, results in a decrease in the number of grains per spike, regardless of the irrigation percentages. This suggests that OP application has a negative impact on grain production within clay soil.

On the other hand, OPBA application in clay soil with 30% irrigation has an effect on the number of grains per spike similar to that of the control. However, with 100% irrigation, OPBA application slightly increases the number of grains per spike compared to the control. This indicates that OPBA application, particularly with higher irrigation levels, may promote grain development and lead to an increase in the number of grains per spike in clay soil.

For OP+OPBA application in clay soil, the number of grains per spike is lower than OPBA application but higher than OP application. This suggests that the mix application has a moderate effect on grain production in clay soil.

Moving to sandy loam soil, there is a significant difference in the number of grains per spike between the two irrigation percentages. The 100% irrigation results in a much higher number of grains per spike compared to the 30% irrigation.

The OP application in sandy loam soil drastically decreases the number of grains per spike compared to the control, indicating a negative effect on grain development and yield.

OPBA application in sandy loam soil shows similar results to the control, suggesting that it does not have a significant impact on the number of grains per spike in sandy loam soil.

The OP+OPBA application in sandy loam soil falls between the effects of OP and OPBA applications, with a higher number of grains per spike compared to OP but lower than OPBA.

According to a study conducted by Brunetti et al. (2005) on wheat (Triticum turgidum L.), it was observed that Soil application of OP determines a significant increase of grains per spike.

In summary, the results indicate that the application type, soil type, and irrigation percentage significantly affect the number of grains per spike. Higher irrigation percentages generally lead to increased grain production. OP application tends to reduce the number of grains per spike, while OPBA application, particularly with higher irrigation levels, can promote grain development and increase the number of grains per spike. The OP+OPBA application falls between these extremes. These findings emphasize the importance of considering application types, soil conditions, and irrigation levels when aiming to optimize grain production and yield. The effect of treatments on number of grains per spike is given in Fig 4.5.

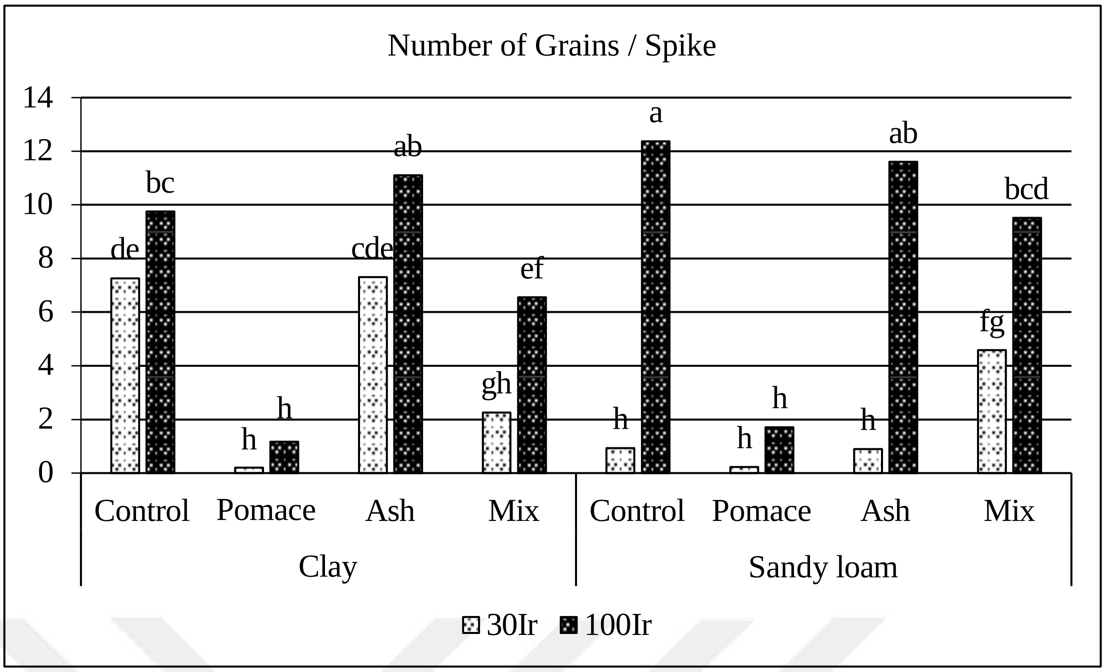

Figure 4.5. The effect of treatments on the number of grains per spike.

4.1.6. Weight of Grains per Spike

The three factors interaction significantly ($p<0.01$) affected the weight of grains per spike.

Regarding the irrigation percentage, both clay soil and sandy loam soil show higher results in the weight of grain per spike with 100% irrigation compared to lower percentages.

In clay soil, the application of OP, compared to the control, results in a decrease in the weight of grain per spike, regardless of the irrigation percentages. This suggests that OP application has a negative impact on grain development and leads to a reduction in the weight of grain per spike in clay soil.

On the other hand, OPBA application in clay soil with 30% irrigation has an effect on the weight of grain per spike that is similar to that of the control. However, with 100% irrigation, OPBA application slightly increases the weight of grain per spike compared to the control. This indicates that OPBA application, particularly with higher irrigation levels, may promote grain development and lead to an increase in the weight of grain per spike in clay soil.

For OP+OPBA application in clay soil, the weight of grain per spike is lower than OPBA application but higher than OP application. This suggests that the OP+OPBA application has a moderate effect on grain development in clay soil.

Moving to sandy loam soil, there is a significant difference in the weight of grain per spike between the two irrigation percentages. The 100% irrigation results in a much higher weight of grain per spike compared to the 30% irrigation.

The OP application in sandy loam soil drastically decreases the weight of grain per spike compared to the control, indicating a negative effect on grain development and yield.

OPBA application in sandy loam soil shows similar results to the control, suggesting that it does not have a significant impact on the weight of grain per spike in sandy loam soil.

The OP+OPBA application in sandy loam soil falls between the effects of OP and OPBA applications, with a higher weight of grain per spike compared to OP but lower than OPBA.

In summary, the results indicate that the application type, soil type, and irrigation percentage significantly affect the weight of grain per spike. Higher irrigation percentages generally lead to increased grain development and weight. OP application tends to reduce the weight of grain per spike, while OPBA application, particularly with higher irrigation levels, can promote grain development and increase the weight of grain per spike. The OP+OPBA application falls between these extremes. These findings emphasize the importance of considering application types, soil conditions, and irrigation levels when aiming to optimize grain development and yield. The effect of treatments on weight of grains per spike is given in Fig 4.6.

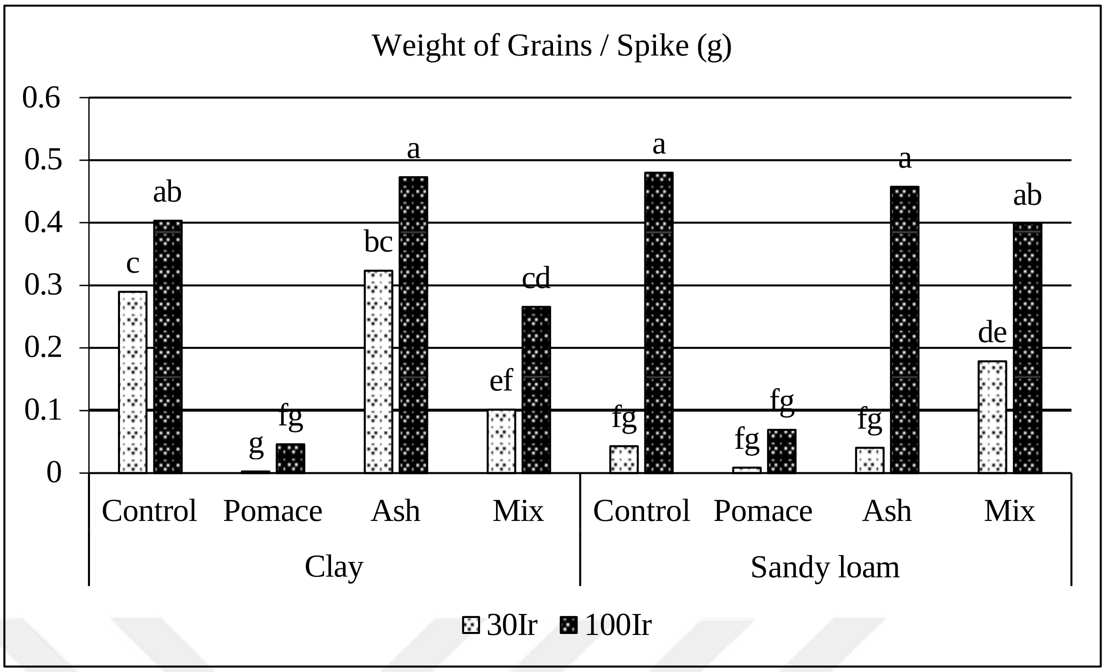

Figure 4.6. The effect of treatments on the weight of grains per spike.

4.1.7. Weight of 1000 Grain

The three factors interaction significantly ($p<0.05$) affected the weight of 1000 grain.

The highest weight of 1000 grains is observed in the control of sandy loam soil with 30% irrigation percentage. This suggests that this specific combination of sandy loam soil and 30% irrigation creates favorable conditions for grain development and leads to a higher weight of 1000 grains.

For OPBA application in both soils with 30% irrigation percentage, there is an increase in the weight of 1000 grains compared to the clay soil control. However, there is a decrease in the weight of 1000 grains compared to the sandy loam soil control. This indicates that OPBA application, particularly with 30% irrigation, can have a positive impact on grain development, resulting in a higher weight of 1000 grains in clay soil but lower weight in sandy loam soil.

Regarding the OP+OPBA application in clay soil with 30% irrigation percentage, there is equality in the weight of 1000 grains compared to the control. This suggests that the OP+OPBA application has a neutral effect on grain weight in this particular condition.

In contrast, OP application in both soils with 100% irrigation and OPBA application in sandy loam soil with 100% irrigation result in a decrease in the weight of 1000 grains compared to the clay soil 100% irrigation control. This indicates that these specific combinations of OP and OPBA application with higher irrigation levels negatively affect grain development and lead to a lower weight of 1000 grains.

Notably, OP application in clay soil with 30% irrigation shows the lowest weight of 1000 grains compared to all other conditions. This suggests that this particular combination hampers grain development and results in the lowest weight of 1000 grains observed.

In summary, the results indicate that the factors studied have significant effects on the weight of 1000 grains. The control of sandy loam soil with 30% irrigation yields the highest weight, while OPBA application with 30% irrigation shows an increase compared to the clay soil control but a decrease compared to the sandy loam soil control. The OP+OPBA application has a neutral effect in clay soil with 30% irrigation. OP application in both soils with 100% irrigation and OPBA application in sandy loam soil with 100% irrigation result in a decrease compared to the clay soil 100% irrigation control. OP application in clay soil with 30% irrigation shows the lowest weight of 1000 grains. These findings underscore the importance of considering soil type, irrigation levels, and application types in optimizing grain weight and overall crop yield. The effect of treatments on weight of 1000 grains is given in Fig 4.7.

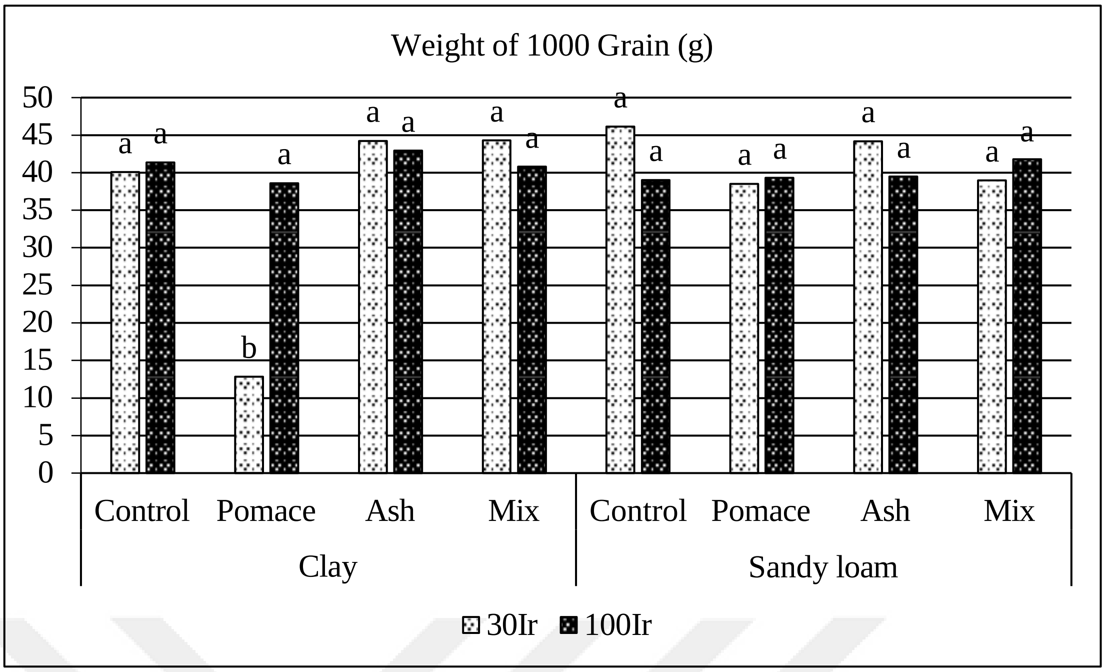

Figure 4.7. The effect of treatments on the weight of 1000 grain.

4.1.8. Weight of Grains per Pot

The three factors interaction significantly ($p<0.01$) affected the weight of grains per pot.

Both clay soil and sandy loam soil show higher results in the weight of grain per pot with 100% irrigation compared to lower percentages.

In clay soil, the application of OP, compared to the control, leads to a decrease in the weight of grain per pot, regardless of the irrigation percentages. This suggests that OP application negatively affects grain development and leads to a reduction in the weight of grain per pot in clay soil.

On the other hand, OPBA application in clay soil with 30% irrigation has an effect on the weight of grain per pot that is nearly the same as the clay control. However, with 100% irrigation, OPBA application slightly increases the weight of grain per pot compared to the control. This indicates that OPBA application, particularly with higher irrigation levels, may promote grain development and lead to an increase in the weight of grain per pot in clay soil.

For OP+OPBA application in clay soil, the weight of grain per pot is lower than OPBA application but higher than OP application. This suggests that the OP+OPBA application has a moderate effect on grain development in clay soil.

Moving to sandy loam soil, there is a significant difference in the weight of grain per pot between the two irrigation percentages. The 100% irrigation results in a much higher weight of grain per pot compared to the 30% irrigation.

The OP application in sandy loam soil drastically decreases the weight of grain per pot compared to the control, indicating a negative effect on grain development and yield.

OPBA application in sandy loam soil shows similar results to the control, suggesting that it does not have a significant impact on the weight of grain per pot in sandy loam soil.

The OP+OPBA application in sandy loam soil falls between the effects of OP and OPBA applications, with a higher weight of grain per pot compared to OP but lower than OPBA.

In a study conducted by Assaf et al. (2009) on chickpea (Cicer arietinum L.), and a study conducted by Brunetti et al. (2005) on wheat (Triticum turgidum L.), it was observed that the OP increased seed yield in chickpea, and total and grain dry yields in wheat.

In summary, the results indicate that the application type, soil type, and irrigation percentage significantly affect the weight of grain per pot. Higher irrigation percentages generally lead to increased grain development and weight. OP application tends to reduce the weight of grain per pot, while OPBA application, particularly with higher irrigation levels, can promote grain development and increase the weight of grain per pot. The OP+OPBA application falls between these extremes. These findings emphasize the importance of considering application types, soil conditions, and irrigation levels when aiming to optimize grain development and yield. The effect of treatments on weight of grains per pot is given in Fig 4.8.

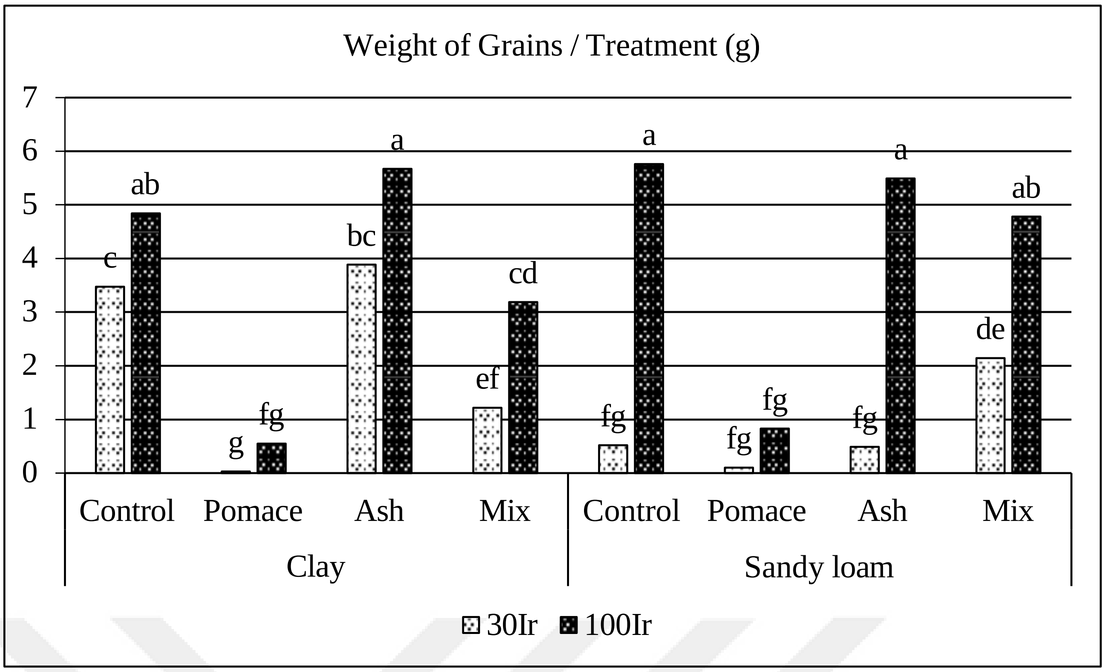

Figure 4.8. The effect of treatments on the weight of grains per pot.

4.1.9. Harvest Index

The three factors interaction significantly ($p<0.01$) affected the harvest index.

Among the treatments, the OP+OPBA application in both soils under 100% irrigation shows the highest harvest index. This indicates that the OP+OPBA application promotes efficient allocation of resources and leads to a higher proportion of yield compared to the total biomass.

For OPBA application in both soils with 100% irrigation, the harvest index is similar to the control for both soils under the same irrigation percentage. However, the harvest index is lower than the OP+OPBA application under the same percentage of irrigation. This suggests that OPBA application does not significantly affect the partitioning of resources towards yield production, resulting in a harvest index comparable to the control but lower than the OP+OPBA application.

In clay soil, both OPBA and OP+OPBA applications under 30% irrigation yield similar harvest index results as the control for the same soil and irrigation percentage. Interestingly, the harvest index for the OP+OPBA application in sandy loam soil under 30% irrigation is also similar to these values. This suggests that under these conditions, resource allocation towards yield production remains similar among these treatments.

OP application in both soils under 100% irrigation shows a lower harvest index compared to the previous mentioned applications. This indicates that OP application may lead to a less efficient allocation of resources towards grain production, resulting in a lower harvest index.

In sandy loam soil, the control and OPBA application under 30% irrigation yield a lower harvest index compared to the OP application in both soils under 100% irrigation. This suggests that under these conditions, OP application allows for better resource allocation towards grain production, resulting in a higher harvest index compared to the control and OPBA application.

Notably, OP application in both soils under 30% irrigation shows the lowest harvest index among all treatments. This indicates that under these specific conditions, OP application leads to a less efficient partitioning of resources towards grain production, resulting in the lowest harvest index observed.

According to a study conducted by Assaf et al. (2009) on (Cicer arietinum L.) under field conditions, it was observed that there is no significant differences were detected for harvest index in response to OP application. While Brunetti et al. (2005) observed a small but not significant increase of harvest index in wheat (Triticum turgidum L.).

In summary, the results indicate that the application type, soil type, and irrigation percentage significantly affect the harvest index. The OP+OPBA application under 100% irrigation shows the highest harvest index, while OPBA application yields comparable results to the control but lower than the OP+OPBA application. OP application generally leads to lower harvest index values. These findings emphasize the importance of considering application types and their effects on resource allocation when aiming to optimize the harvest index, as it reflects the efficiency of converting biomass into grain yield. The effect of treatments on harvest index is given in Fig 4.9.

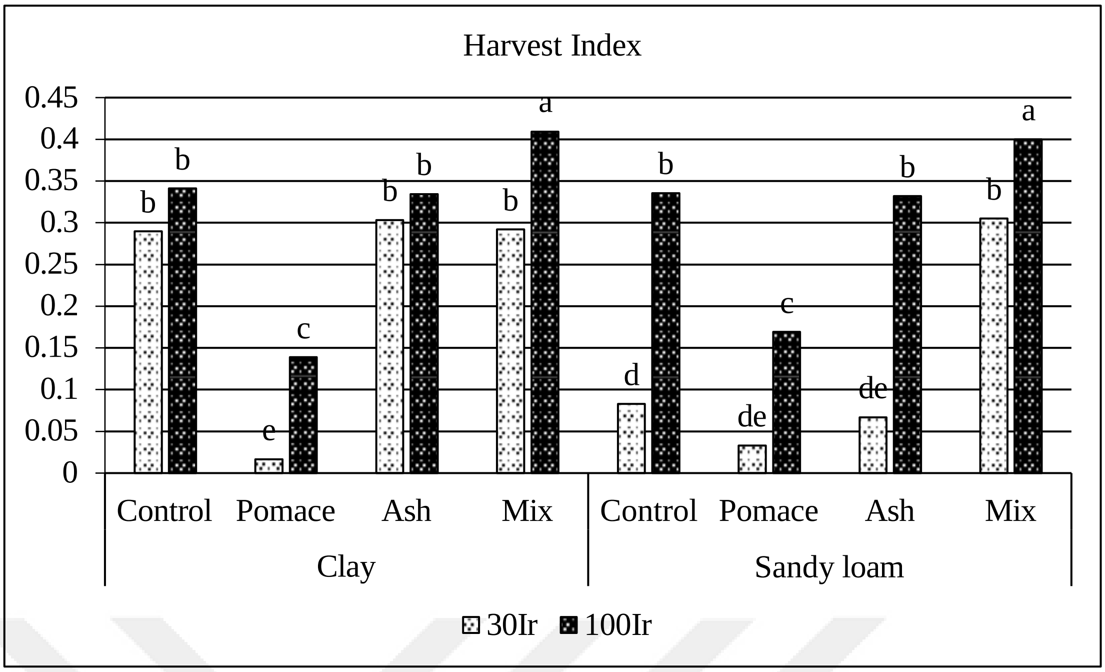

Figure 4.9. The effect of treatments on the harvest index.

4.1.10. Cumulative Evapotranspiration (mL)

The results examines the effects of the factors on cumulative evapotranspiration. When considering the three factors together, no significant effect is observed. However, when considering all other factors together, a significant effect on cumulative evapotranspiration is observed.

Regarding the soil type, evapotranspiration in clay soil, regardless of the irrigation percentage and application type, is slightly higher than in sandy loam soil. This could be attributed to the differences in soil characteristics and water-holding capacity between the two soil types, which influence the rate of evapotranspiration.

Regarding the irrigation percentage, evapotranspiration under 100% irrigation in both soils is higher than under 30% irrigation. This is expected since higher irrigation levels provide more water availability for plants, leading to increased evapotranspiration rates.

Regarding the application type, evapotranspiration under OPBA application in both soils, with the two irrigation percentages, shows similar results to the control. This suggests that OPBA application does not significantly affect the evapotranspiration rate compared to the control conditions. On the other hand, the OP+OPBA application results in slightly lower evapotranspiration compared to the control. This may indicate that the OP+OPBA application affects plant water use efficiency or alters the balance between transpiration and evaporation processes.

For OP application in both soils under 30% irrigation, it exhibits the lowest evapotranspiration among the other treatments. This could be due to the influence of OP on plant water requirements, root development, or transpiration rates. However, under 100% irrigation, the evapotranspiration for OP application is higher than the OP+OPBA application under 30% irrigation, indicating a different response to higher water availability.

In summary, when considering the three factors together, no significant effect on cumulative evapotranspiration is observed. However, when considering all other factors together, significant differences are observed. Evapotranspiration in clay soil is slightly higher than in sandy loam soil. Higher irrigation percentages result in increased evapotranspiration rates. OPBA application does not significantly affect evapotranspiration, while the OP+OPBA application leads to slightly lower rates. OP application generally decreases evapotranspiration, with the lowest rates observed under 30% irrigation. These findings highlight the importance of considering soil type, irrigation levels, and application types when studying cumulative evapotranspiration in order to optimize water use efficiency and manage irrigation practices effectively. The effect of treatments on cumulative evapotranspiration is given in Fig 4.10.

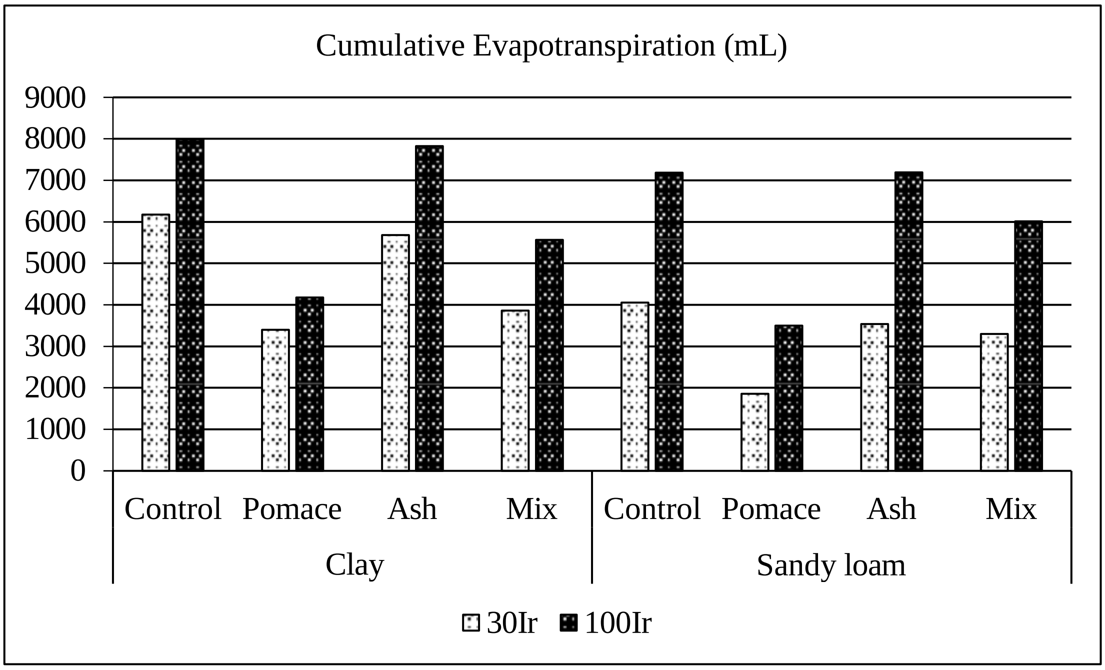

Figure 4.10. The effect of treatments on the cumulative evapotranspiration.

4.1.11. Germination Percentage

The the results examines the effects of the factors on germination percentage. When considering interaction of the three factors together, no significant effect is observed. However, significant differences are observed among soil types and application types.

Regarding soil types, the germination percentage in clay soil is higher than in sandy loam soil. This could be attributed to differences in soil characteristics such as nutrient availability, water-holding capacity, and seedbed conditions, which can influence the germination process and overall germination success.

In terms of irrigation percentages, the germination percentage in clay soil is generally higher under 100% irrigation compared to 30% irrigation, except for the OP+OPBA application under 30% irrigation, which shows a higher germination percentage. This suggests that higher irrigation levels, particularly in clay soil, promote favorable conditions for seed germination, ensuring better moisture availability and nutrient uptake for seedling development.

For sandy loam soil, the germination percentage is generally higher under 30% irrigation compared to 100% irrigation, except for the OP+OPBA application under 100% irrigation, which shows a higher germination percentage. This may be due to the sandy loam soil's inherent characteristics, such as good drainage and faster water infiltration rates, which can facilitate seed germination under lower irrigation levels.

Regarding the application types, OPBA application in both soils and under both irrigation percentages shows a higher germination percentage compared to the OP+OPBA application and OP application. This suggests that OPBA application provides favorable conditions for seed germination, potentially due to the presence of essential nutrients and favorable pH levels.

The highest germination percentage in clay soil is observed in the control with 100% irrigation, indicating that the natural soil conditions, along with higher water availability, contribute to optimal germination success. Similarly, in sandy loam soil, the highest germination percentage is observed in the control with 30% irrigation, suggesting that the inherent soil characteristics, combined with adequate moisture levels, are favorable for successful seed germination.

In comparison, OP application in clay soil generally shows higher germination numbers than the OP+OPBA application, whereas in sandy loam soil, OP application shows lower numbers compared to the OP+OPBA application. This indicates that the influence of OP on seed germination may vary depending on the soil type and its specific characteristics.

According to a study conducted by Killi & Kavdir. (2013) on tomato (Solanum lycopersicum), it was observed that seed germination in loamy soil was not significantly affected by the application of OP, while 8% application of OP in sandy soils resulted in a significant 26.7% increase in seed germination.

In summary, the results indicate that there is no significant effect when considering interaction of the three factors together on germination percentage. However, significant differences are observed among soil types and application types. Clay soil generally shows higher germination percentages, and higher irrigation levels tend to promote germination in clay soil, while lower irrigation levels are more favorable for germination in sandy loam soil. OPBA application generally leads to higher germination percentages compared to the OP+OPBA application and OP application. These findings emphasize the importance of considering soil type and application types when aiming to optimize germination success and establish successful seedlings. The effect of treatments on germination percentages is given in Fig 4.11.

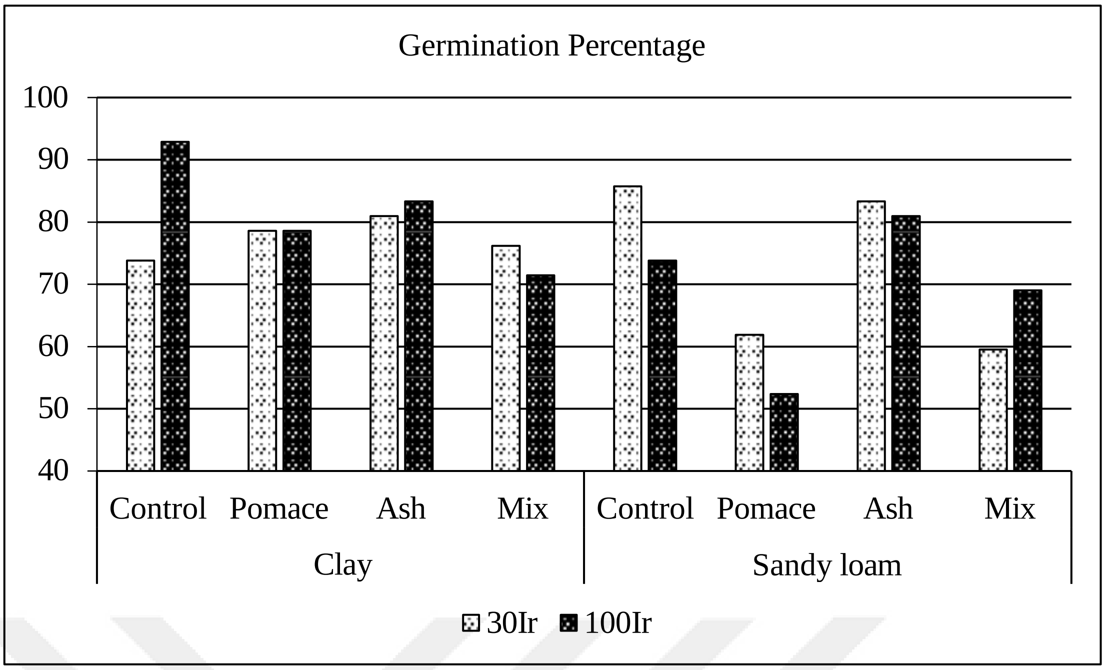

Figure 4.11. The effect of treatments on the germination percentage.

4.1.12. Water Use Efficiency

The results examines the effects of the factors on water use efficiency, and it shows a significant ($p<0.01$) effect of the interaction between the three factors. Water use efficiency is an important indicator of how effectively plants utilize water to produce biomass and yield.

OPBA application in clay soil with 30% irrigation and the sandy loam soil control with 100% irrigation exhibit the highest water use efficiency. This suggests that these specific combinations of OPBA application and irrigation levels optimize water use and result in a higher proportion of biomass and yield per unit of water consumed.

For OPBA application in both soils, along with 100% irrigation, there is a slightly decreased water use efficiency compared to OPBA application in clay soil with 30% irrigation. However, the water use efficiency is higher than the control in clay soil with both percentages of irrigation. This indicates that OPBA application, particularly with 30% irrigation, enhances water use efficiency and promotes better conversion of water into biomass in both soils.

On the other hand, OP application in both soils, with both irrigation percentages, shows the lowest water use efficiency among the treatments, except for OP in sandy loam soil with 30% irrigation, which exhibits higher values. This suggests that OP application may not effectively utilize water resources, resulting in a lower proportion of biomass and yield per unit of water consumed. The specific conditions of sandy loam soil with 30% irrigation might provide more favorable conditions for OP application, leading to relatively higher water use efficiency compared to other treatments.

The OP+OPBA application in sandy loam soil, with both irrigation percentages, shows higher values of water use efficiency compared to the OP+OPBA application in clay soil. This suggests that the OP+OPBA application, in the context of sandy loam soil, enhances water use efficiency and promotes more efficient utilization of water resources for biomass production.

In summary, the results indicate that there is a significant effect of the interaction between the three factors on water use efficiency. OPBA application in clay soil with 30% irrigation and the sandy loam soil control with 100% irrigation show the highest water use efficiency. OPBA application in both soils, along with 100% irrigation, exhibits slightly decreased water use efficiency compared to the OPBA application in clay soil with 30% irrigation. OP application generally leads to lower water use efficiency, except in sandy loam soil with 30% irrigation. The OP+OPBA application in sandy loam soil shows higher water use efficiency compared to the OP+OPBA application in clay soil. These findings highlight the importance of considering application types, irrigation levels, and soil characteristics to optimize water use efficiency and improve agricultural practices. The effect of treatments on water use efficiency is given in Fig 4.12.

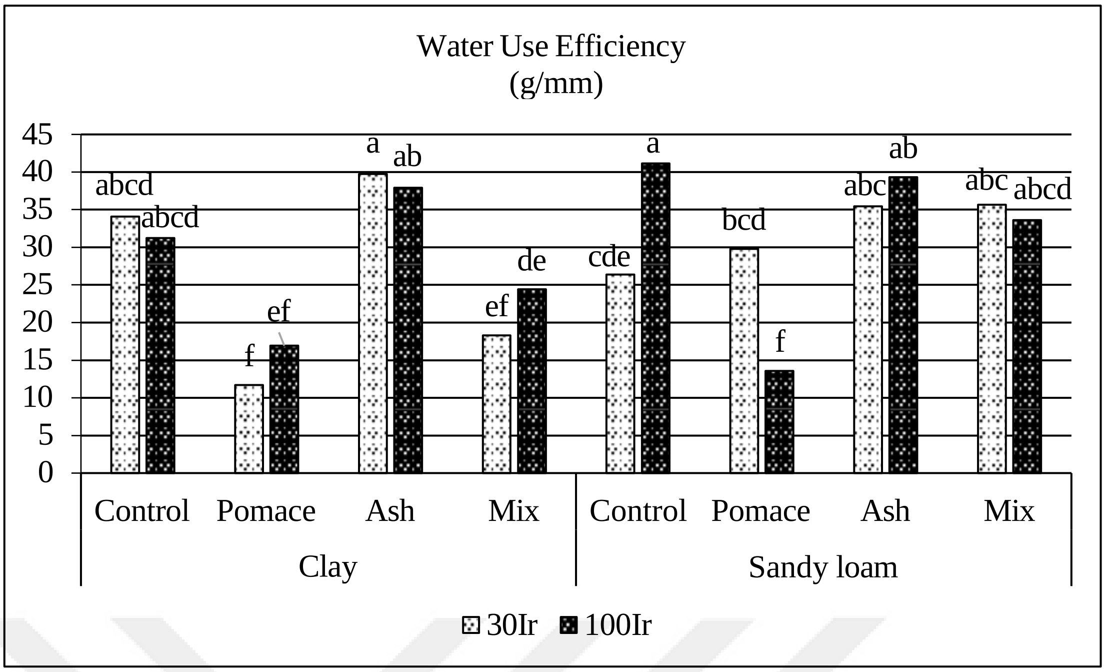

Figure 4.12. The effect of treatments on the water use efficiency.

4.2. The Effect of Treatments on Soil Physical Properties

4.2.1. Soil Bulk Density

The results indicate that there is no significant effect for the interaction between the three factors on soil bulk density. However, significant differences are observed based on soil type, irrigation percentages, and application types.

Regarding soil type, the soil bulk density in sandy loam soil is higher than in clay soil. This can be attributed to the inherent characteristics of sandy loam soil, which typically has larger particles and lower organic matter content, leading to a higher bulk density compared to clay soil. The average bulk density in clay soil is approximately 1.05 g/cc, while in sandy loam soil, it ranges between 1.15 and 1.20 g/cc.

In terms of irrigation percentages, the soil bulk density in both soils with 30% irrigation is slightly higher than with 100% irrigation. This can be explained by the fact that lower irrigation levels may result in less water movement within the soil, leading to a more compacted soil structure and slightly higher bulk density.

Regarding application types, in sandy loam soil, the OP application shows a bulk density similar to the control but higher than the OPBA and OP+OPBA application. This indicates that OP application may not significantly influence soil compaction in sandy loam soil. On the other hand, the OP+OPBA application in sandy loam soil exhibits the lowest soil bulk density among the application types. This suggests that the OP+OPBA application may contribute to better soil structure and reduced compaction in sandy loam soil.

In clay soil, the bulk density is nearly the same across all application types. This suggests that the application types may have minimal influence on soil compaction in clay soil, possibly due to the inherent soil characteristics and the dominant role of clay particles in determining the bulk density.

According to a study conducted by Adriano & Weber. (2001), it was found that there is no apparent effect of fly ash application on soil bulk density.

In summary, the results indicate that there is no significant effect for the interaction between the three factors on soil bulk density. However, significant differences are observed based on soil type, irrigation percentages, and application types. Sandy loam soil generally exhibits higher bulk density compared to clay soil. Lower irrigation levels may lead to slightly higher bulk density in both soils. In sandy loam soil, the OP+OPBA application shows the lowest bulk density, while in clay soil, the application types have minimal influence on bulk density. These findings highlight the importance of considering soil type and management practices to maintain optimal soil structure and prevent excessive compaction that can hinder plant growth and root development. The effect of treatments on soil bulk density is given in Fig 4.13.

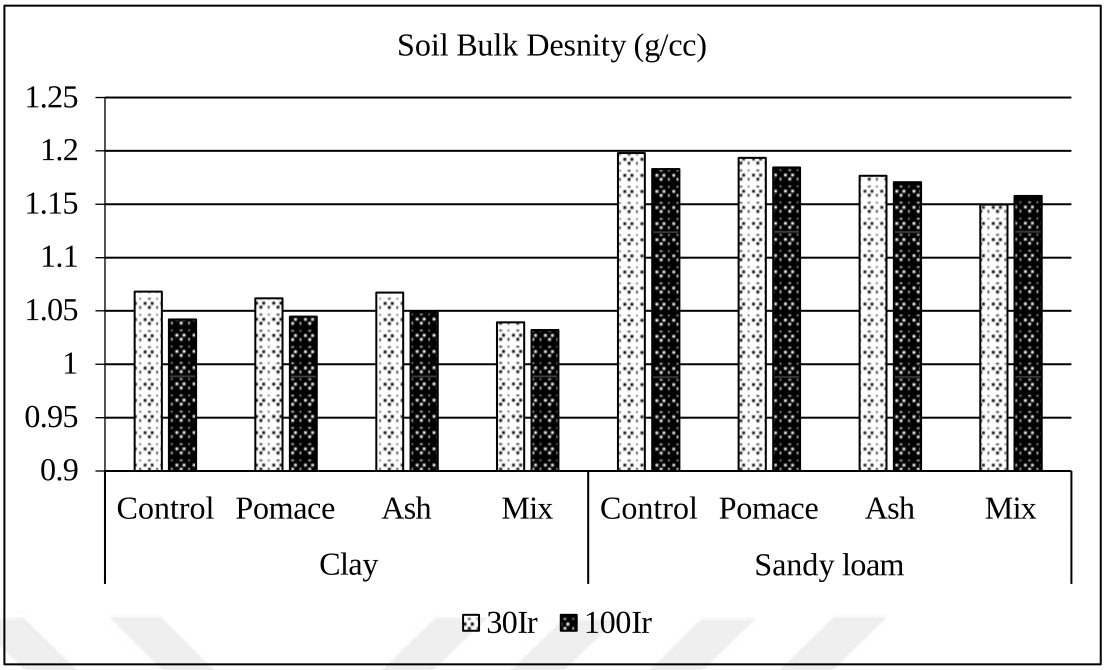

Figure 4.13. The effect of treatments on the soil bulk density.

4.2.2. Soil Porosity

While there is no significant effect for the interaction between the three factors on soil porosity, significant differences are observed based on soil type, irrigation percentage, the interaction between soil type and irrigation percentage, application type, and the interaction between soil type and application type.

Regarding soil type, the graph shows that clay soil generally has higher soil porosity compared to sandy loam soil. This can be attributed to the higher clay content in clay soil, which creates more inter-particle spaces and results in a higher porosity. The porosity of sandy loam soil falls between 0.55 and 0.57, while clay soil exhibits a range between 0.59 and 0.61.

In terms of irrigation percentage, the soil porosity under 100% irrigation is slightly higher than under 30% irrigation in both soil types. This could be due to the higher water content associated with increased irrigation levels, resulting in expanded soil pore spaces and higher overall porosity.

Regarding the application type, the OP+OPBA application consistently exhibits the highest soil porosity in clay soil with both percentages of irrigation, as well as in both soils overall. This suggests that the OP+OPBA application enhances soil structure and creates favorable conditions for increased porosity. The other application types generally show similar soil porosity values as the control, indicating that they do not significantly alter the soil pore structure.

For OPBA application, in clay soil, it has similar soil porosity as the control, suggesting that OPBA application does not significantly affect soil pore spaces in clay soil. In sandy loam soil, however, OPBA application results in higher soil porosity compared to the control but lower than the OP+OPBA application. This indicates that OPBA application may have some positive influence on soil porosity in sandy loam soil, but it is not as effective as the OP+OPBA application.

OP application shows similar values of soil porosity as the control, indicating that it has minimal impact on the pore structure of the soil.

In summary, the results indicate that while there is no significant effect for the interaction between the three factors on soil porosity, significant differences are observed based on soil type, irrigation percentage, the interaction between soil type and irrigation percentage, application type, and the interaction between soil type and application type. Clay soil generally exhibits higher porosity compared to sandy loam soil. Higher irrigation levels result in slightly higher porosity. The OP+OPBA application consistently leads to the highest soil porosity, while the other application types show similar values to the control. OPBA application has some positive influence on sandy loam soil porosity but not as much as the OP+OPBA application. OP application has minimal effect on soil porosity. These findings highlight the importance of considering soil type and management practices to maintain optimal soil porosity, as it plays a crucial role in water infiltration, nutrient availability, and root development. The effect of treatments on soil porosity is given in Fig 4.14.

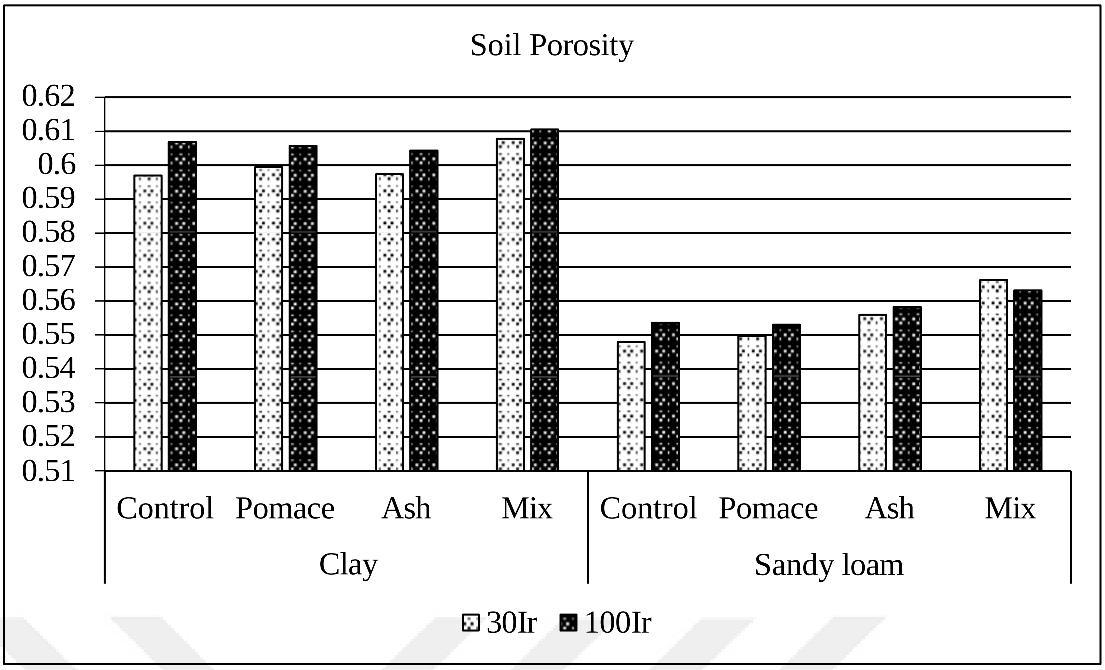

Figure 4.14. The effect of treatments on the soil porosity.

4.2.3. Soil Aggregate Stability

The results show a significant ($p<0.01$) effect for the interaction between the three factors.

In terms of soil type, clay soil exhibits higher aggregate stability than sandy loam soil. This can be attributed to the higher clay content in clay soil, which promotes the formation of stable soil aggregates and improves soil structure.

Among the treatments, OP application in clay soil with 100% irrigation appears to have the highest aggregate stability. This suggests that the application of OP in clay soil, combined with adequate irrigation, enhances the formation and stability of soil aggregates, potentially due to its organic matter content and beneficial effects on soil structure.

On the other hand, in clay soil, the OPBA application with 30% irrigation shows the lowest aggregate stability compared to the clay soil control. This suggests that the OPBA application, specifically with 30% irrigation in clay soil, may negatively affect aggregate stability, potentially due to its impact on soil structure or other factors.

In sandy loam soil, the situation is reversed. The sandy loam soil control with 30% irrigation and OPBA application to sandy loam soil under 30% irrigation show higher aggregate stability compared to the sandy loam soil control and OPBA application with 100% irrigation. This indicates that lower irrigation levels, along with the sandy loam soil's inherent characteristics, promote better aggregate stability in sandy loam soil.

Furthermore, the OP+OPBA application in sandy loam soil demonstrates higher aggregate stability compared to the other treatments in sandy loam soil. This suggests that the OP+OPBA application contributes to improved soil structure, promoting the formation of stable soil aggregates in sandy loam soil.

According to a study conducted by Killi & Kavdir. (2013), on sandy and loamy soils, it was observed that the increase in soil OM induced by application of OP had a positive effect on sandy soil aggregate stability, and had less effect in the loamy soil.

In summary, the results indicate a significant effect for the interaction between the three factors on soil aggregate stability. Clay soil generally exhibits higher aggregate stability compared to sandy loam soil. OP application in clay soil with 100% irrigation shows the highest aggregate stability, while OPBA application in clay soil with 30% irrigation exhibits the lowest aggregate stability among the clay soil treatments. In sandy loam soil, the control with 30% irrigation, along with OPBA application under 30% irrigation, shows higher aggregate stability compared to the sandy loam soil control and OPBA application with 100% irrigation. The OP+OPBA application in sandy loam soil demonstrates higher aggregate stability compared to other treatments in sandy loam soil. These findings underscore the importance of considering soil type, irrigation levels, and application types to enhance soil aggregate stability and improve soil structure for sustainable agricultural practices. The effect of treatments on soil aggregate stability is given in Fig 4.15.

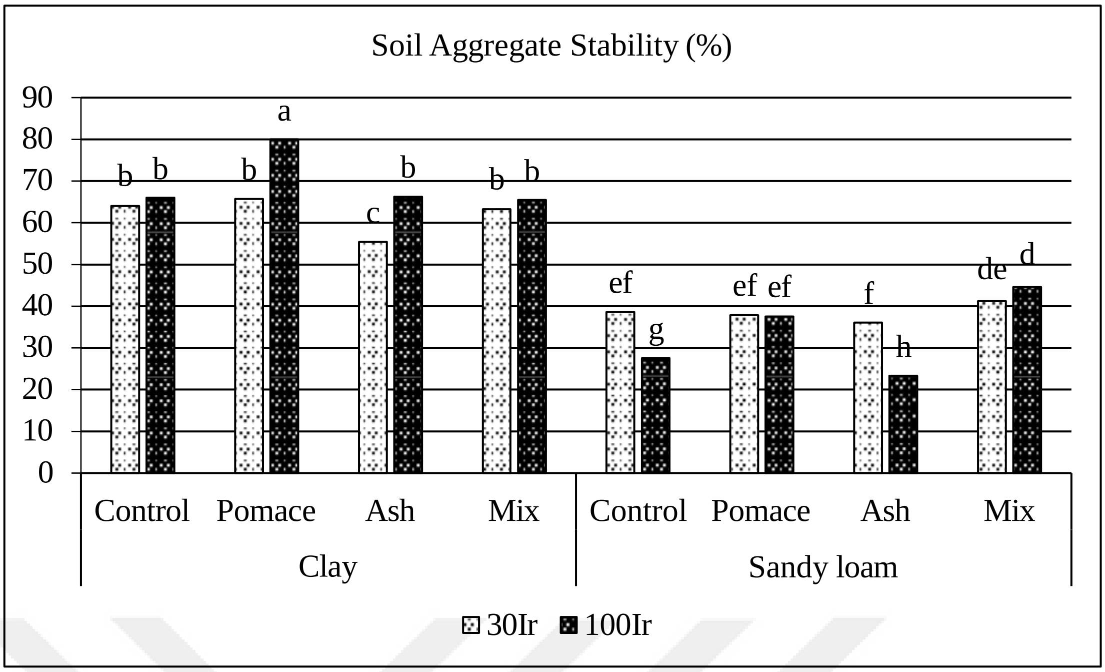

Figure 4.15. The effect of treatments on the soil aggregate stability.

4.2.4. Soil Structure Stability Index

The results examines the effects of the factors on the soil structure stability index. While there is no significant effect for the interaction between the three factors on the soil stability index, there are significant differences based on soil type and application type.

In terms of soil type, the clay soil demonstrates a higher structure stability index compared to the sandy loam soil. This can be attributed to the higher clay content in clay soil, which plays a crucial role in forming stable soil aggregates and enhancing the overall structural stability. On the other hand, sandy loam soil, with its higher sand content, tends to have weaker soil structure and lower structure stability index.

Regarding application types, the results indicate that there is a slight effect on the structure stability index in both soils. OP application shows slightly higher structure stability index than the other application types. This may be due to the organic matter content of OP, which can contribute to the formation of stable soil aggregates and improve soil structure.

In contrast, OPBA application slightly decreases the structure stability index in both soils compared to the control. This could be attributed to the specific properties of OPBA and its impact on the soil structure. It is possible that OPBA application disrupts the soil aggregates and reduces the overall stability of the soil structure.

In summary, while there is no significant effect for the interaction between the three factors on the soil structure stability index, significant differences are observed based on soil type and application type. Clay soil exhibits higher structure stability index compared to sandy loam soil, likely due to the higher clay content. OP application shows slightly higher structure stability index, potentially due to its organic matter content and positive influence on soil aggregation. Conversely, OPBA application slightly decreases the structure stability index in both soils, potentially due to its impact on soil structure. These findings highlight the importance of considering soil type and management practices, such as organic matter application, to enhance soil structure stability and promote sustainable agricultural practices. The effect of treatments on soil structure stability index is given in Fig 4.16.

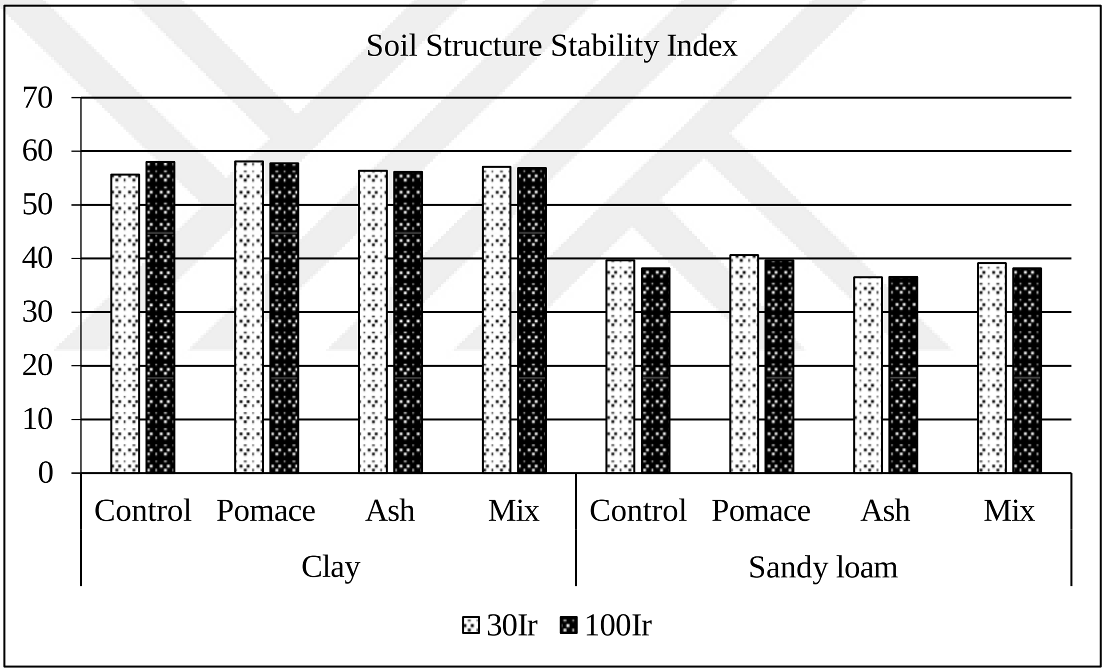

Figure 4.16. The effect of treatments on the soil structure stability index.

4.2.5. Soil Dispersion Ratio

The results examines the effects of the factors on the soil dispersion ratio. While there is no significant effect for the interaction between the three factors on the soil dispersion ratio, there are significant differences based on soil type and application type.

In terms of soil type, the sandy loam soil demonstrates a higher dispersion ratio compared to the clay soil. This can be attributed to the higher sand content in sandy loam soil, which tends to have particles that are more prone to dispersion. On the other hand, clay soil, with its higher clay content, generally exhibits better aggregation and lower dispersion ratio.

Regarding application types, the results indicate that there is a slight effect on the soil dispersion ratio. Application types with 100% irrigation show a slightly higher dispersion ratio compared to those with 30% irrigation. This may be due to the increased availability of water in the soil, which can contribute to the dispersion of soil particles.

Among the application types, the OPBA application in both soils shows the highest dispersion ratio. This suggests that the OPBA application has a negative impact on soil structure and promotes the dispersion of soil particles. On the other hand, the OP application in both soils exhibits the lowest dispersion ratio. This may be attributed to the organic matter content of OP, which can enhance soil aggregation and reduce particle dispersion.

The OP+OPBA application falls between the OP and OPBA applications in terms of dispersion ratio for both soil types. This indicates that the OP+OPBA application has a moderate effect on soil dispersion, likely influenced by the combination of factors present in the OP+OPBA.

In summary, while there is no significant effect for the interaction between the three factors on the soil dispersion ratio, significant differences are observed based on soil type and application type. Sandy loam soil generally exhibits a higher dispersion ratio compared to clay soil due to its higher sand content. Application types with 100% irrigation show slightly higher dispersion ratios compared to those with 30% irrigation. OPBA application has the highest dispersion ratio, indicating its negative impact on soil structure. OP application shows the lowest dispersion ratio, likely due to its organic matter content and positive influence on soil aggregation. The OP+OPBA application falls in between the two extremes. These findings highlight the importance of considering soil type and management practices to mitigate soil dispersion and promote stable soil structure for sustainable agricultural practices. The effect of treatments on soil dispersion ratio is given in Fig 4.17.

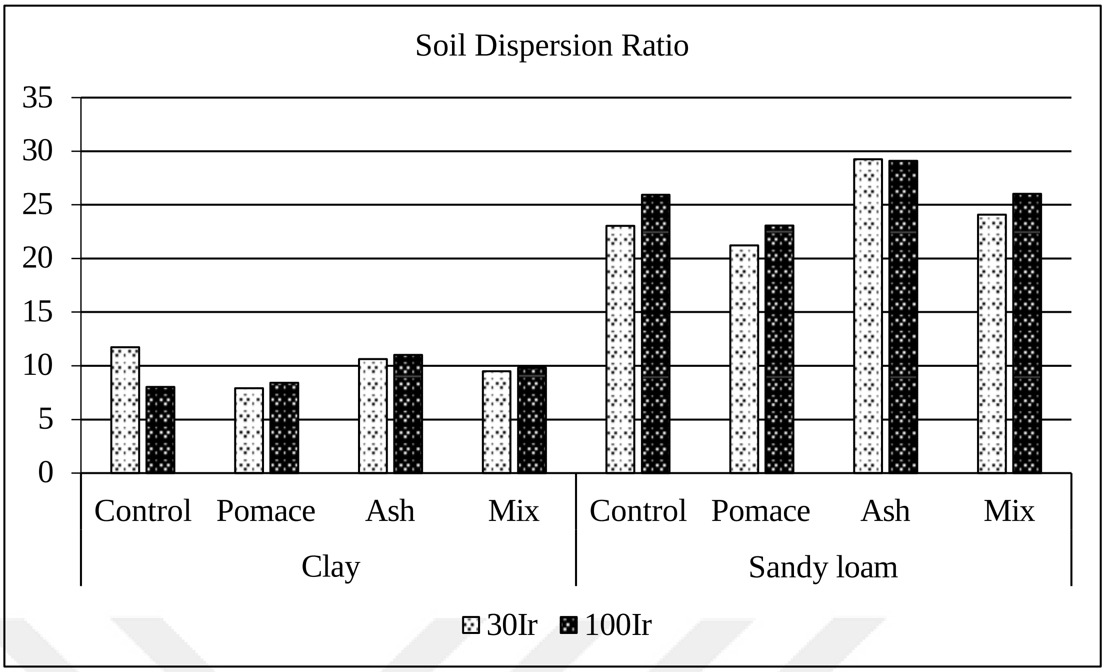

Figure 4.17. The effect of treatments on the soil dispersion ratio.

4.2.6. Soil Crust Formation

The results examines the effects of the factors on soil crust formation. While there is no significant effect for the interaction between the three factors on soil crust formation, there are significant differences based on soil type, application type, and the interaction between soil type and application type.

In terms of soil type, the results indicate that crust formation is higher in sandy loam soil compared to clay soil. This can be attributed to the sandy loam soil's characteristics, such as its higher sand content, which makes it more prone to crust formation due to the lack of fine particles that aid in soil aggregation and stability. On the other hand, clay soil generally has better aggregation and a lower tendency to form crusts.

Regarding application types, the results indicate that the application of OP in both soils increases soil crust formation compared to the control. This suggests that the organic matter content of OP may contribute to the development of a crust on the soil surface.

In clay soil, the OPBA application shows higher crust formation compared to the clay soil control. This may be due to the specific properties of OPBA and its impact on soil structure, leading to increased crust formation. However, in sandy loam soil, the OPBA application shows lower crust formation compared to the sandy loam soil control. The reasons for this discrepancy could be attributed to the interactions between OPBA and the sandy loam soil's characteristics, resulting in different crust formation outcomes.

The OP+OPBA application in clay soil shows similar crust formation as the control, indicating that it does not significantly affect crust formation in clay soil. However, in sandy loam soil, the OP+OPBA application exhibits slightly higher crust formation than the sandy loam soil control. This suggests that the OP+OPBA application may have some impact on crust formation in sandy loam soil, potentially due to the specific combination of factors present in the OP+OPBA.

In summary, while there is no significant effect for the interaction between the three factors on soil crust formation, significant differences are observed based on soil type, application type, and the interaction between soil type and application type. Sandy loam soil generally exhibits higher crust formation compared to clay soil. The application of OP increases crust formation in both soils. The OPBA application shows higher crust formation in clay soil but lower crust formation in sandy loam soil. The OP+OPBA application has minimal effect on crust formation in clay soil but slightly increases crust formation in sandy loam soil. These findings emphasize the importance of considering soil type and management practices to mitigate soil crust formation and maintain a healthy soil surface for sustainable agricultural practices. The effect of treatments on soil crust formation is given in Fig 4.18.

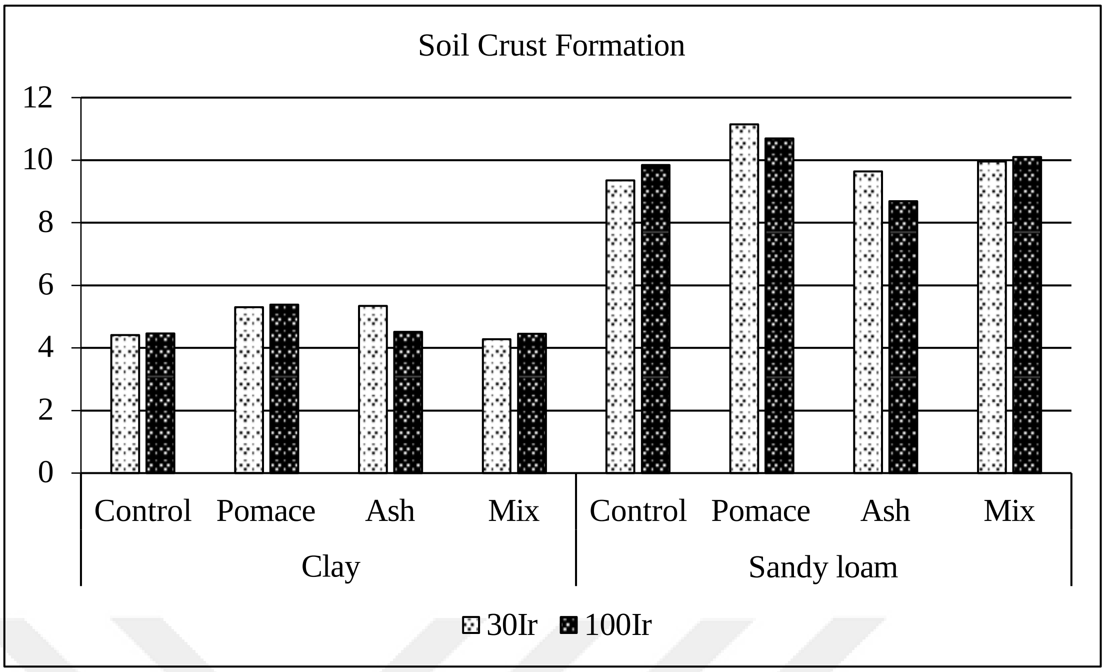

Figure 4.18. The effect of treatments on the soil crust formation.

4.2.7. Soil Penetration Resistance

The results examines the effects of the factors on soil penetration resistance. While there is no significant effect for the interaction between the three factors on soil penetration resistance, there are significant differences based on soil type, irrigation percentage, the interaction between soil type and irrigation percentage, and the interaction between soil type and application type.

Comparing the two soil types, the results show higher penetration resistance values in sandy loam soil compared to clay soil. This can be attributed to the sandy loam soil's characteristics, such as its higher proportion of sand particles, which typically have a higher bulk density and reduced pore space, resulting in greater resistance to penetration.

In clay soil, the 100% irrigation condition exhibits significantly higher penetration resistance values compared to the 30% irrigation condition across all application types. This suggests that higher irrigation levels in clay soil can lead to increased compaction, resulting in higher resistance to penetration.

In sandy loam soil, the 100% irrigation condition shows slightly higher penetration resistance values compared to the 30% irrigation condition in control, OP, and OPBA application. This may be due to increased moisture content and subsequent compaction caused by higher irrigation levels. However, under the OP+OPBA application in sandy loam soil, the 30% irrigation condition exhibits higher penetration resistance compared to the 100% irrigation condition. This could be attributed to the specific characteristics of the OP+OPBA application and its impact on soil structure.

Comparing the application types in clay soil, the results indicate that the OP application results in significantly lower levels of penetration resistance compared to the clay soil control. On the other hand, the OPBA and OP+OPBA application show similar and slightly lower penetration resistance levels compared to the control. These differences can be attributed to the organic matter content of OP, which can enhance soil structure and reduce compaction, resulting in lower penetration resistance.

In sandy loam soil, all the application types show higher penetration resistance values compared to the sandy loam soil control, but at varying levels. This suggests that the application types have different impacts on soil structure and compaction in sandy loam soil.

In summary, while there is no significant effect for the interaction between the three factors on soil penetration resistance, significant differences are observed based on soil type, irrigation percentage, and the interactions between soil type and irrigation percentage, and soil type and application type. Sandy loam soil generally exhibits higher penetration resistance compared to clay soil due to its sandier composition. Higher irrigation levels in clay soil lead to increased penetration resistance. The application types have varying effects on penetration resistance in both soil types. OP application reduces penetration resistance in clay soil, while OPBA and OP+OPBA application show similar or slightly lower values. In sandy loam soil, all the application types result in higher penetration resistance compared to the control, but at different levels. These findings highlight the importance of considering soil type, irrigation practices, and application types to manage soil compaction and promote optimal soil penetration for sustainable agricultural practices. The effect of treatments on soil penetration resistance is given in Fig 4.19.

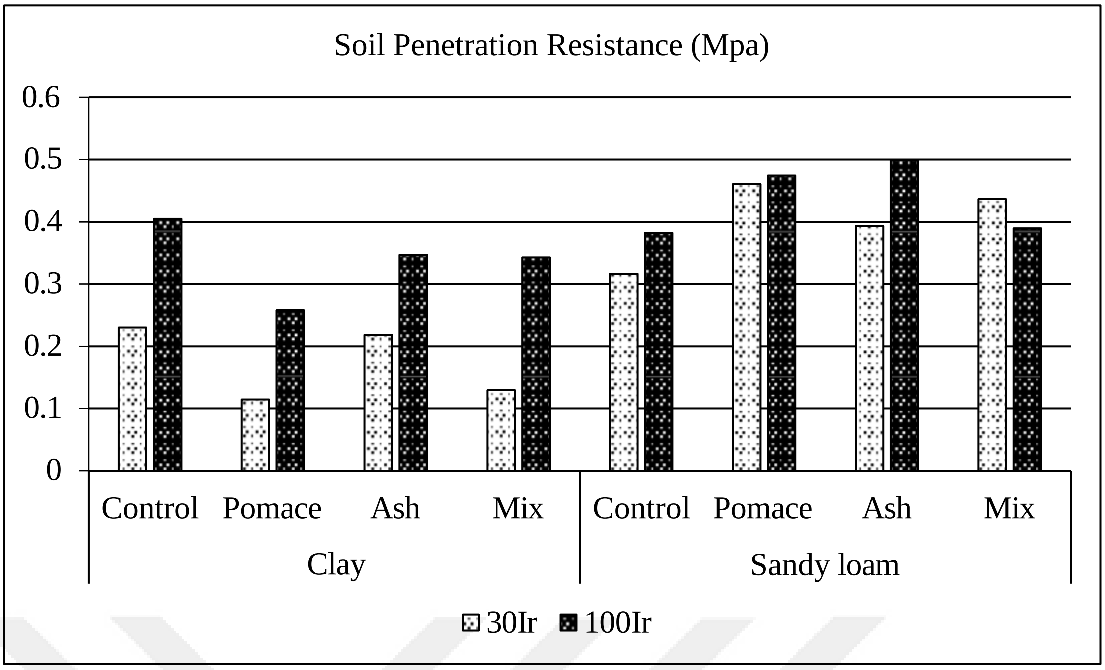

Figure 4.19. The effect of treatments on the soil penetration resistance.

4.2.8. Soil Moisture Content at Field Capacity

The results examines the effects of the factors on soil moisture content at field capacity. While there is no significant effect for the interaction between the three factors on soil moisture content, there is a significant difference based on soil type.

The results indicate that the clay soil has a higher moisture content at field capacity compared to the sandy loam soil. This can be attributed to the inherent characteristics of the soil types. Clay soil has smaller particle sizes and higher water-holding capacity, allowing it to retain more moisture at field capacity. On the other hand, sandy loam soil has larger particle sizes and lower water-holding capacity, resulting in lower moisture content at field capacity.

Interestingly, the results show that the irrigation percentage and the application types do not have a significant effect on the soil moisture content at field capacity. This suggests that regardless of the irrigation level or the type of application used, the soil moisture content at field capacity remains relatively consistent. This could be due to the saturation point of the soils being reached under field capacity conditions, resulting in little variation in moisture content.

In summary, while there is no significant effect for the interaction between the three factors on soil moisture content at field capacity, there is a significant difference based on soil type. Clay soil exhibits higher moisture content at field capacity compared to sandy loam soil due to its finer texture and higher water-holding capacity. The irrigation percentage and application types do not significantly affect the soil moisture content at field capacity, indicating that the saturation point of the soils may have been reached under field capacity conditions. These findings highlight the importance of considering soil type and understanding its inherent characteristics when assessing soil moisture dynamics and irrigation management for optimal crop growth and water conservation. The effect of treatments on soil moisture content at field capacity is given in Fig 4.20.

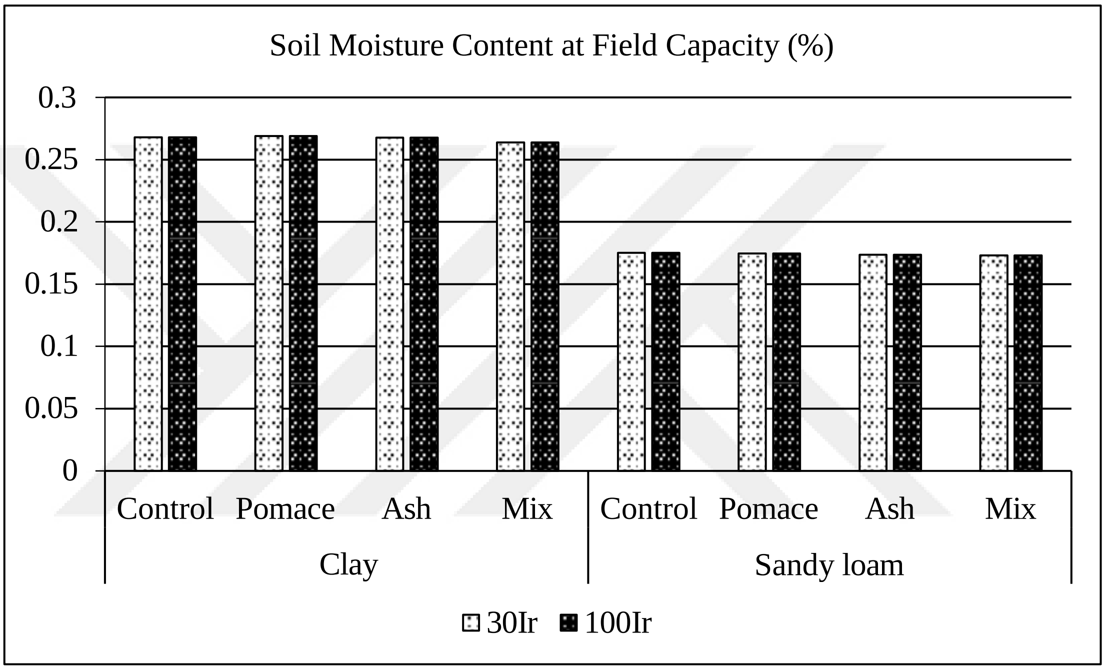

Figure 4.20. The effect of treatments on the soil moisture content at field capacity.

4.2.9. Soil Moisture Content at Permanent Wilting Point

The results examines the effects of the factors on soil moisture content at permanent wilting point. While there is no significant effect for the interaction between the three factors on soil moisture content, there is a significant difference based on soil type.

The results indicate that the clay soil has a higher moisture content at permanent wilting point compared to the sandy loam soil. This can be attributed to the inherent characteristics of the soil types. Clay soil has smaller particle sizes and higher water-holding capacity, allowing it to retain more moisture even at the point where plants are unable to extract water from the soil, known as the permanent wilting point. On the other hand, sandy loam soil has larger particle sizes and lower water-holding capacity, resulting in lower moisture content at the permanent wilting point.

Interestingly, the results show that the irrigation percentage and the application types do not have a significant effect on the soil moisture content at the permanent wilting point. This suggests that regardless of the irrigation level or the type of application used, the soil moisture content at the permanent wilting point remains relatively consistent. This could be due to the inherent characteristics of the soil types and the point at which plants can no longer extract water from the soil.

In summary, while there is no significant effect for the interaction between the three factors on soil moisture content at the permanent wilting point, there is a significant difference based on soil type. Clay soil exhibits higher moisture content at the permanent wilting point compared to sandy loam soil due to its finer texture and higher water-holding capacity. The irrigation percentage and application types do not significantly affect the soil moisture content at the permanent wilting point, indicating that the inherent characteristics of the soil types play a more significant role in determining the moisture availability for plants at this critical stage. These findings emphasize the importance of understanding soil type and its inherent water-holding capacity for effective irrigation management and crop water requirements. The effect of treatments on soil moisture content at permanent wilting point is given in Fig 4.21.

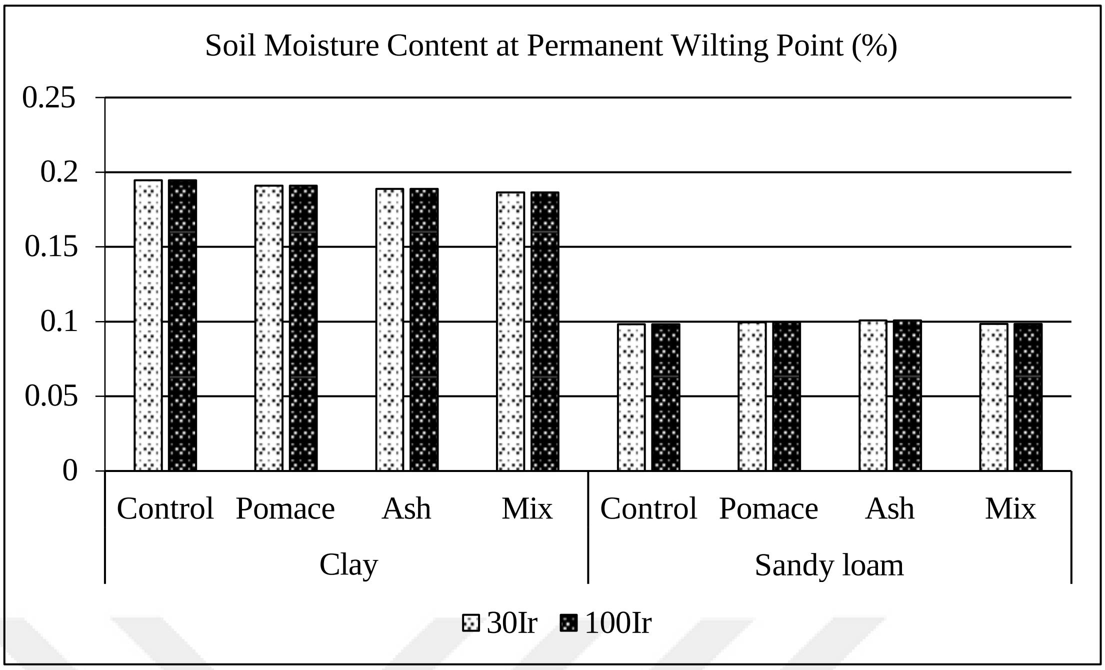

Figure 4.21. The effect of treatments on the soil moisture content at permanent wilting point.

4.2.10. Plant Available Water Capacity

The results examines the effects of the factors on plant available water. The results indicate that there is no significant effect for the interaction between the three factors on plant available water. This implies that the combination of soil type, irrigation percentage, and application type does not have a noticeable impact on the plant available water.

Interestingly, all the treatments show nearly the same range of plant available water, ranging from 0.07 to 0.08. This suggests that regardless of the soil type, irrigation percentage, or application type, the available water for plants remains consistent within this range. This could be attributed to factors such as soil composition, soil moisture retention characteristics, and the ability of plants to extract water from the soil.

The lack of significant differences among the treatments in terms of plant available water could indicate that the experimental factors chosen for this study do not strongly influence water availability for plant growth. Other factors not considered in this study, such as climate conditions, root characteristics, or plant species, may have a more significant influence on plant available water.

According to a study conducted by Adriano & Weber. (2001), it was observed that the primarily silt-size prevalence of the fly ash used evidently enhanced PAW and WHC of soil.

In summary, the results indicate that the three factors, soil type, irrigation percentage, and application type, do not have a significant effect on plant available water. The observed range of plant available water across all treatments suggests a consistent water availability for plant growth. This may be due to other factors not considered in this study playing a more prominent role in determining plant available water. Further investigation into additional factors could provide a more comprehensive understanding of water availability for plants in this experimental setup. The effect of treatments on plant available water capacity is given in Fig 4.22.

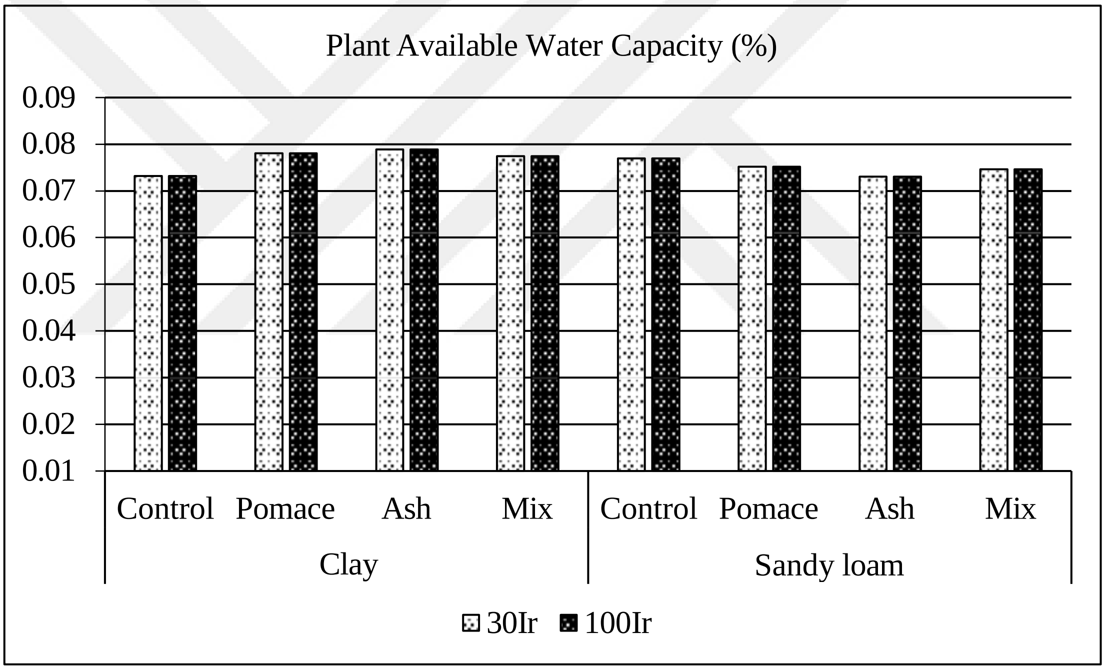

Figure 4.22. The effect of treatments on plant available water capacity.

4.3. The Effect of Treatments on Soil Chemical Properties

4.3.1. Soil Reactions (pH)

The results examines the effects of the factors on soil pH. While there is no significant effect for the interaction between the three factors on soil pH, there is a significant difference based on the application type.

The results show that the soil pH values across the treatments range from 7.25 to 7.55. Interestingly, the application type has a significant effect on the soil pH.

Specifically, the OPBA application in both soils results in the highest pH values among the treatments, indicating a more alkaline soil environment. On the other hand, the OP and OP+OPBA application show similar pH values, which are slightly lower than the control.

The differences in soil pH among the application types can be attributed to the chemical properties of the applied materials. OPBA application often contains alkaline components, such as calcium carbonate, which can raise the pH of the soil. This increase in pH may be responsible for the higher pH values observed in the OPBA - treated soils. On the other hand, the OP and OP+OPBA application may have minimal impact on the soil pH, resulting in pH values that are slightly lower than the control.

It is important to note that soil pH plays a crucial role in nutrient availability and microbial activity in the soil. Different plant species have varying pH preferences, and soil pH can affect the availability and uptake of essential nutrients by plants. Thus, understanding and managing soil pH is vital for optimal plant growth and productivity.

According to a study conducted by Deenik et al. (2011) on the effect of charcoal ash on acid ultisol, it was observed that increases in soil pH were correlated with charcoal ash content. While in a study conducted by Khan et al. (1996) on the effect of fly ash on soil, it was observed that fly ash decreases soil pH with the increasing of doses.

In summary, while there is no significant effect for the interaction between the three factors on soil pH, the application type has a significant influence on soil pH. The OPBA application results in higher pH values, indicating a more alkaline soil environment, while the OP and OP+OPBA application show slightly lower pH values compared to the control. These findings highlight the importance of considering the application type and its chemical properties when assessing soil pH and its implications for plant growth and nutrient availability. The effect of treatments on soil pH is given in Fig 4.23.

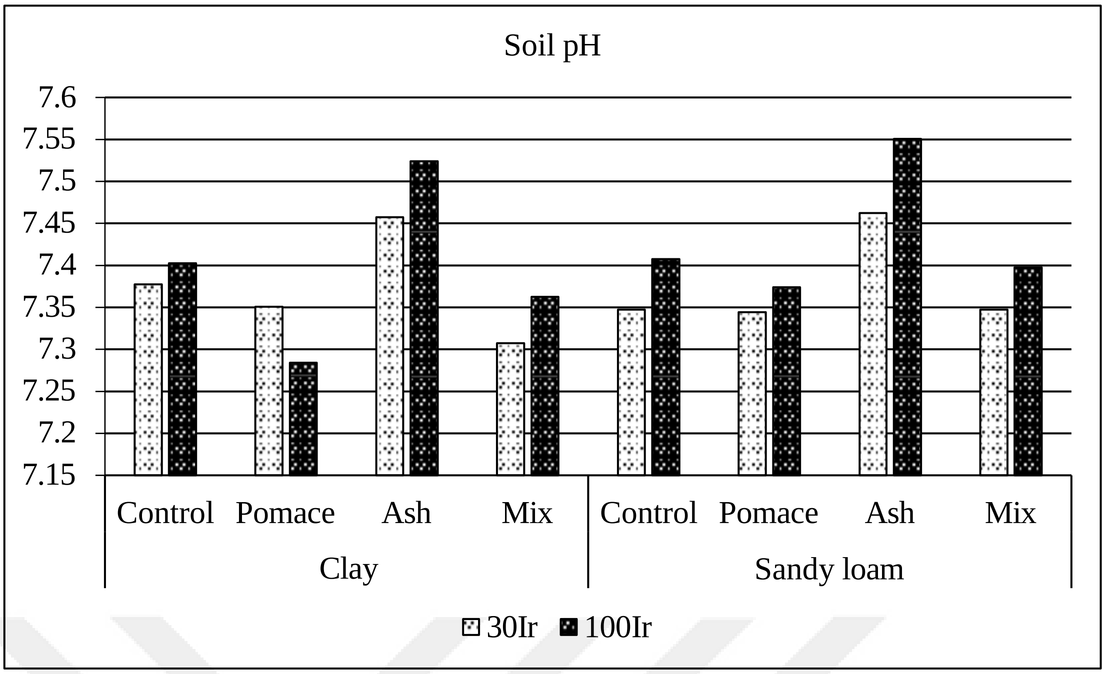

Figure 4.23. The effect of treatments on the soil pH.

4.3.2. Soil Electrical Conductivity (EC)

The results examines the effects of the factors on soil EC. While there is no significant effect for the interaction between the three factors on soil EC, there are significant differences based on soil type and application type.

The results indicate that the EC in sandy loam soil is slightly higher than in clay soil. This difference in EC can be attributed to the inherent characteristics of the soil types. Sandy loam soil generally has larger particle sizes and lower cation exchange capacity, which can lead to leaching and higher EC values. In contrast, clay soil has smaller particle sizes and higher cation exchange capacity, which allows it to retain more nutrients and moisture, resulting in relatively lower EC values.

Additionally, the application type has a significant effect on soil EC. The OP, OPBA, and OP+OPBA applications increased the EC in both soils under the two irrigation percentages. This increase in EC can be attributed to the presence of dissolved ions and salts in the applied materials. These materials may contribute to higher levels of electrical conductivity in the soil solution, leading to an increase in EC.

The measurement of soil EC provides valuable information about the salinity levels in the soil, which can affect nutrient availability and plant growth. It is important to monitor and manage soil salinity to ensure optimal plant health and productivity.

According to a study conducted by Khan et al. (1996) on the effect of fly ash on soil, it was observed that fly ash increase the soil EC with the increasing of doses.

In summary, while there is no significant effect for the interaction between the three factors on soil EC, the soil type and application type have significant influences. The sandy loam soil tends to have slightly higher EC values than the clay soil, likely due to differences in particle size and cation exchange capacity. The OP, OPBA, and OP+OPBA applications increased the EC in both soils, possibly due to the presence of dissolved ions and salts. These findings highlight the importance of considering soil type and the application of materials on soil salinity levels and nutrient management. The effect of treatments on soil EC is given in Fig 4.24.

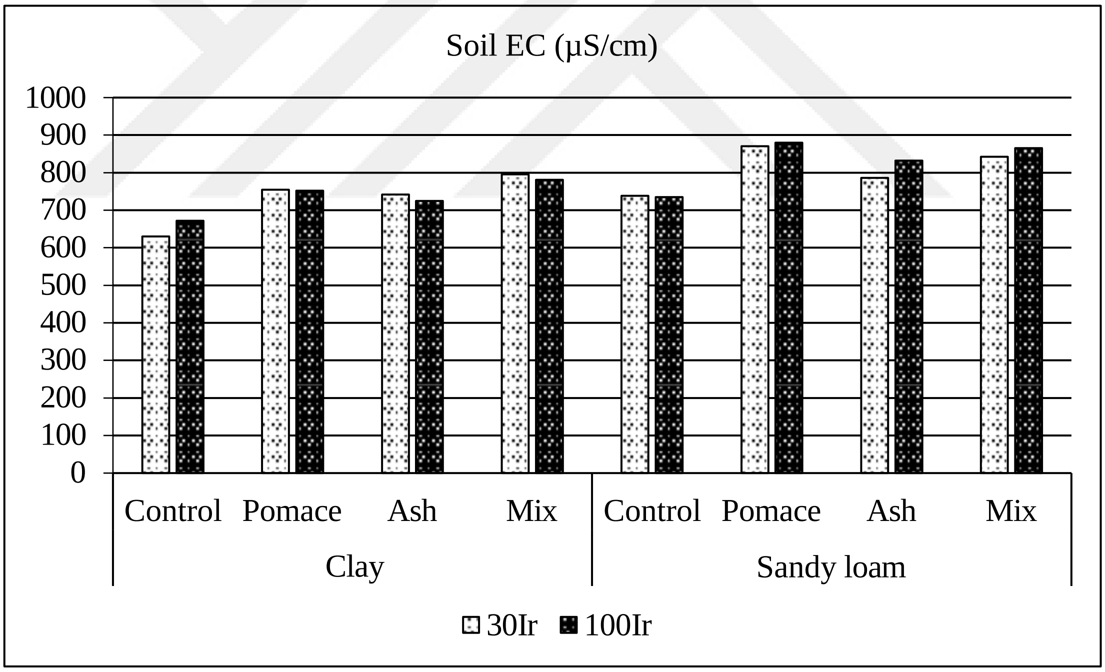

Figure 4.24. The effect of treatments on the soil electrical conductivity (EC).

4.3.3. Soil Organic Matter (OM)

The results examines the effects of the factors on soil organic matter. While there is no significant effect for the interaction between the three factors on soil organic matter, there are significant differences based on soil type, application type, and the interaction between soil type and application type.

The results indicate that the sandy loam soil has higher levels of organic matter compared to the clay soil. This difference can be attributed to several factors, including the composition and texture of the soils. Sandy loam soil typically has a lower clay and organic matter content, which results in a lower capacity to retain organic matter. On the other hand, clay soil has a higher clay content, providing more surface area for organic matter adsorption and retention.

Furthermore, the application type also influences the levels of soil organic matter. The OP application in both soils results in the highest levels of organic matter among the other application types. This can be explained by the organic nature of OP, which is derived from organic materials such as fruit or vegetable waste. The OP application adds organic matter directly to the soil, contributing to higher levels of organic matter content.

In contrast, the OPBA and OP+OPBA application in both soils show similar levels of organic matter compared to the control. This suggests that these application types may not have a substantial impact on increasing organic matter content.

Additionally, the interaction between soil type and application type plays a role in determining the levels of organic matter. For example, in both soils, the application of OPBA under 30% irrigation shows slightly higher levels of organic matter than the OPBA application under 100% irrigation. This interaction effect indicates that the combination of OPBA application and lower irrigation percentage may enhance organic matter levels in the soil.

Soil organic matter is crucial for soil health, fertility, and nutrient cycling. It provides a source of nutrients for plants, improves soil structure, and enhances water-holding capacity. Understanding the factors that influence soil organic matter content is essential for sustainable land management practices.

According to a study conducted by Innangi et al. (2017) on the effect of olive pomace on soil, it was observed that the addition of OP clearly increased soil organic matter content.

In summary, while there is no significant effect for the interaction between the three factors on soil organic matter, the soil type, application type, and the interaction between soil type and application type have significant effects. The sandy loam soil has higher levels of organic matter compared to the clay soil, and the OP application leads to the highest levels of organic matter. The OPBA and OP+OPBA application show similar levels of organic matter compared to the control. The interaction between soil type and application type further influences organic matter content. These findings emphasize the importance of considering soil type and the specific application types when aiming to increase soil organic matter content and improve soil health. The effect of treatments on soil organic matter is given in Fig 4.25.

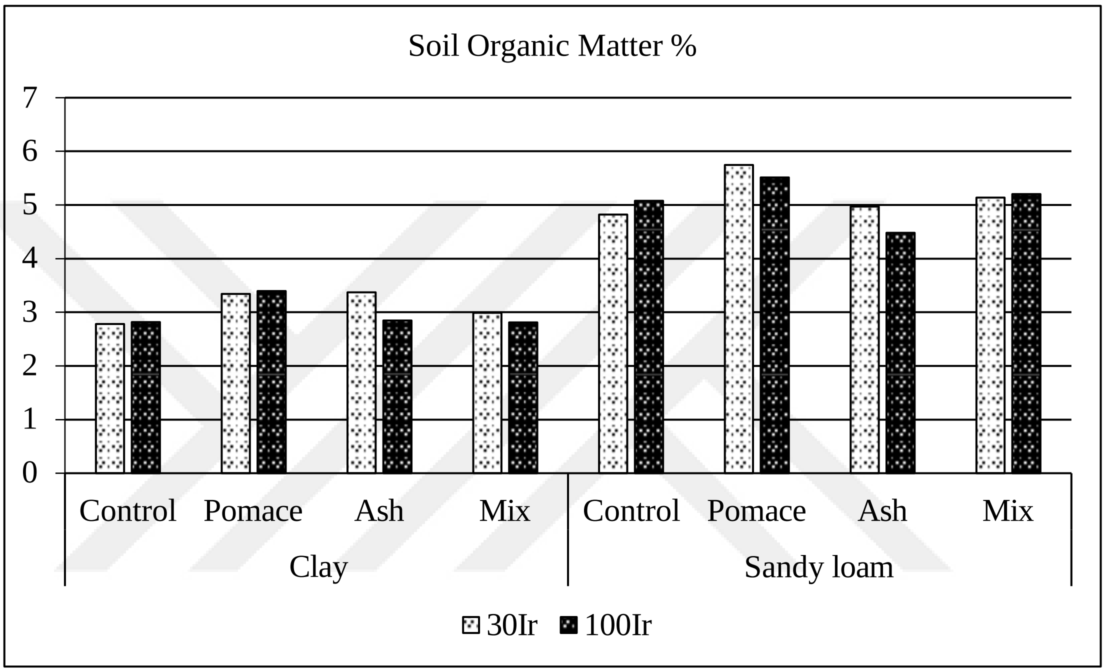

Figure 4.25. The effect of treatments on the soil organic matter (OM) percentage.

4.3.4. Soil Available Phosphorus (P) Content

The results examines the effects of the factors on available phosphorus content. While there is no significant effect for the interaction between the three factors on available phosphorus content, there are significant differences based on soil type, irrigation percentage, the interaction between soil type and irrigation percentage, application type, and the interaction between soil type and application type.

The results indicate that the sandy loam soil has a much higher content of available phosphorus compared to the clay soil. This difference can be attributed to the inherent characteristics of the soil types. Sandy loam soil typically has a lower cation exchange capacity and a higher proportion of coarse particles, which allows for better drainage and lower phosphorus retention. In contrast, clay soil has a higher cation exchange capacity and a greater ability to retain and bind phosphorus, resulting in lower levels of available phosphorus.

Furthermore, the irrigation percentage also plays a role in available phosphorus content. In sandy loam soil, the 100% irrigation tends to have slightly higher available phosphorus content compared to the 30% irrigation. This can be attributed to the increased leaching of nutrients under higher irrigation rates, making phosphorus more readily available. In contrast, in clay soil, the 30% irrigation tends to have slightly higher available phosphorus content compared to the 100% irrigation. This can be explained by the reduced leaching and the improved retention of phosphorus in clay soil under lower irrigation rates.

The application type also influences the available phosphorus content. In clay soil, all application types tend to have similar available phosphorus content, suggesting that the addition of any application type does not significantly impact phosphorus availability. In sandy loam soil, the addition of OP slightly increases the available phosphorus content compared to the control, while the addition of OPBA further increases the content. The OP+OPBA application leads to the highest available phosphorus content among the application types in sandy loam soil. These differences in available phosphorus content can be attributed to the varying phosphorus content and release rates of the applied materials.

Phosphorus is a critical nutrient for plant growth and development. Understanding the factors that influence available phosphorus content is essential for optimizing nutrient management strategies and ensuring adequate phosphorus availability for plant uptake.

According to a study conducted by Ameziane et al. (2019) on the effect of olive pomace on soil fertility, it was observed that the available phosphorus content increased significantly using different percentages of OP.

In summary, while there is no significant effect for the interaction between the three factors on available phosphorus content, the soil type, irrigation percentage, the interaction between soil type and irrigation percentage, application type, and the interaction between soil type and application type have significant effects. The sandy loam soil has significantly higher available phosphorus content compared to the clay soil. The irrigation percentage influences available phosphorus content differently in sandy loam and clay soils. The application type has varying effects on available phosphorus content, with OP, OPBA, and OP+OPBA applications leading to different levels of available phosphorus in sandy loam soil. In clay soil, all application types result in similar available phosphorus content. These findings emphasize the importance of considering soil type, irrigation management, and specific application types when aiming to optimize available phosphorus content and enhance plant nutrient uptake. The effect of treatments on soil available phosphorus content is given in Fig 4.26.

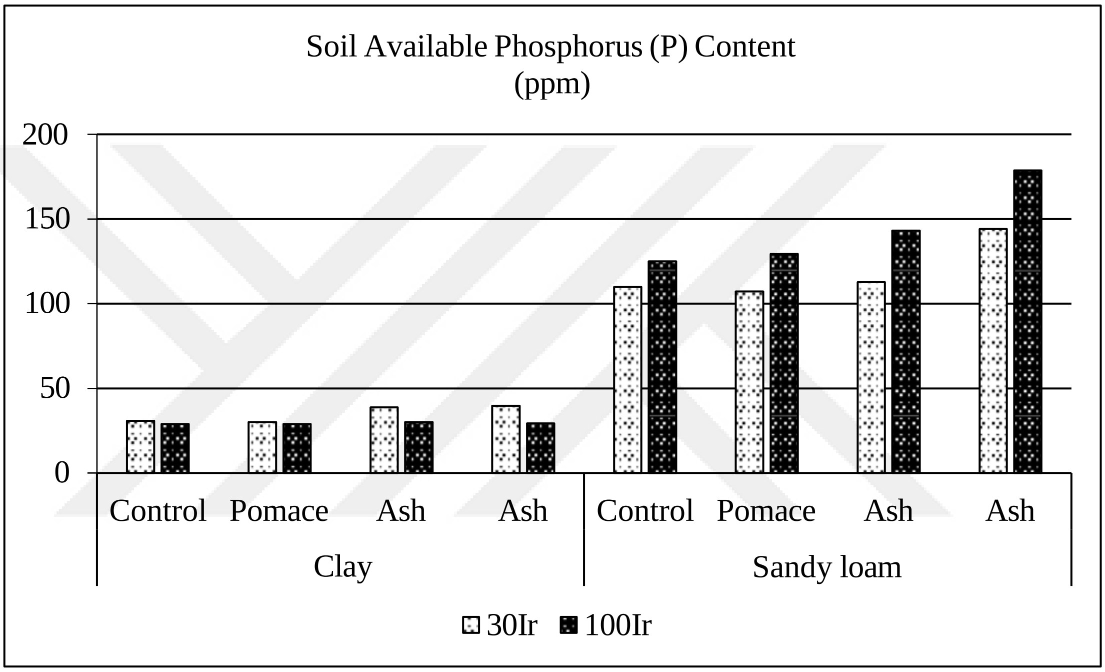

Figure 4.26. The effect of treatments on the soil available phosphorus (P) content.

4.3.5. Soil Cation Exchange Capacity (CEC)

The results examines the effects of the factors on soil cation exchange capacity. While there is no significant effect for the interaction between the three factors on cation exchange capacity, there are significant differences based on soil type and the interaction between soil type and application type.

The results indicate that the clay soil has a higher cation exchange capacity compared to the sandy loam soil. This difference can be attributed to the inherent characteristics of the soil types. Clay soil typically has a higher clay and organic matter content, which contributes to a greater number of negatively charged sites available for cation exchange. These negatively charged sites can hold and exchange cations, allowing clay soil to have a higher cation exchange capacity.

In terms of the application type, the results show different effects on cation exchange capacity based on the soil type. In sandy loam soil, the addition of OP, OPBA, and OP+OPBA does not significantly change the cation exchange capacity. This may be due to the sandy loam soil's lower clay and organic matter content, which limits the number of exchange sites and thus restricts changes in cation exchange capacity upon the addition of different materials.

In contrast, in clay soil, the addition of OP, OPBA, and OP+OPBA tends to slightly increase the cation exchange capacity respectively. This can be attributed to the introduction of organic matter and different cation-exchanging ions in the applied materials. Organic matter enhances the development of clay-humus complexes, which can increase the cation exchange capacity of the soil. Additionally, the specific ions present in the OPBA and OP+OPBA applications may contribute to the slight increase in cation exchange capacity.

Cation exchange capacity plays a crucial role in nutrient availability and retention in the soil. Soils with higher cation exchange capacity have a greater ability to retain and release essential nutrients for plant uptake. Understanding the factors influencing cation exchange capacity helps in managing nutrient availability and optimizing fertilizer applications.

According to a study conducted by Killi & Kavdir. (2013) on the effect of OP on sandy soil and loamy soil, it was observed that the cation exchange capacity increased with the application level in both soils.

In summary, while there is no significant effect for the interaction between the three factors on cation exchange capacity, the soil type and the interaction between soil type and application type have significant effects. The clay soil has a higher cation exchange capacity compared to the sandy loam soil due to its higher clay and organic matter content. In sandy loam soil, the addition of different application types does not significantly affect cation exchange capacity, while in clay soil, the addition of OP, OPBA, and OP+OPBA tends to slightly increase cation exchange capacity. These findings highlight the importance of soil type and the specific materials applied in managing cation exchange capacity and nutrient availability in agricultural systems. The effect of treatments on soil CEC is given in Fig 4.27.

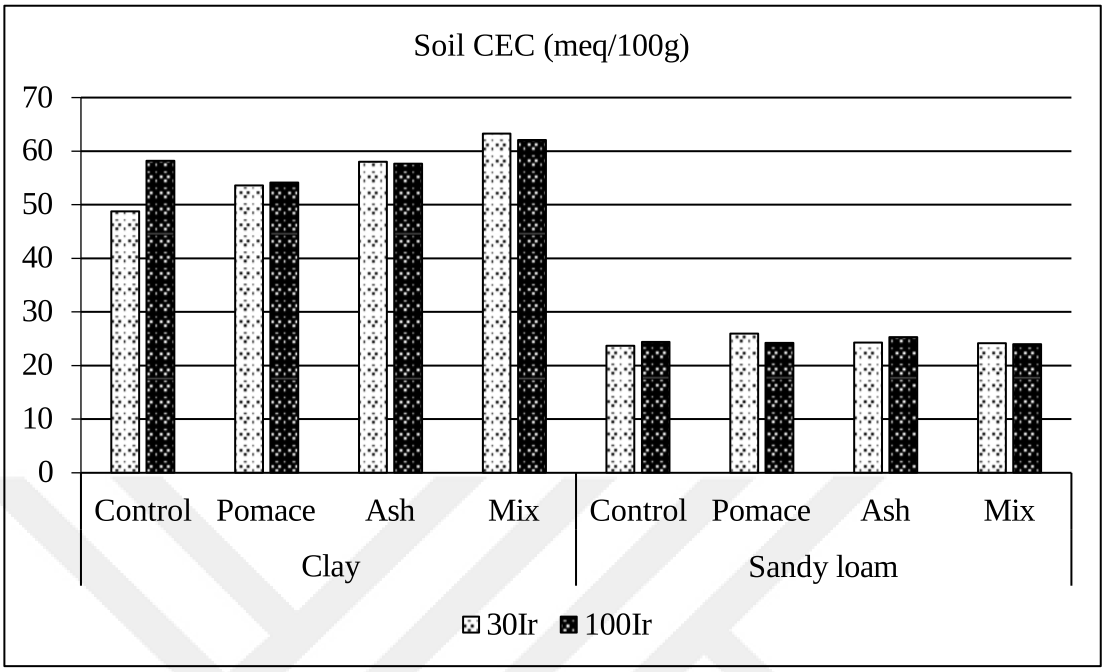

Figure 4.27. The effect of treatments on the soil cation exchange capacity (CEC).

4.3.6. Soil Lime Content ($CaCO_3$)

The results examines the effects of the factors on soil lime content. While there is no significant effect for the interaction between the three factors on lime content, there is a significant difference based on soil type.

The results indicate that the sandy loam soil has much higher levels of lime content compared to the clay soil. This difference can be attributed to the natural composition and geological history of the soils. Sandy loam soils are typically derived from parent materials that contain a higher proportion of calcium carbonate (lime). Over time, weathering and erosion processes contribute to the accumulation of lime in sandy loam soils, leading to higher lime content. On the other hand, clay soils are often formed from different parent materials and may have a lower inherent lime content.

Lime content is an important factor in soil pH regulation and nutrient availability. Soils with higher lime content tend to have a higher pH, making them more alkaline. This alkaline pH can affect nutrient availability, microbial activity, and overall soil fertility. Sandy loam soils with their higher lime content may exhibit alkaline pH conditions, which can have implications for plant growth and nutrient management.

It is important to consider lime content when making soil management decisions, such as nutrient application and soil amendments. Understanding the lime content of the soil can help determine appropriate lime application rates, especially in clay soils where lime content is typically lower. Lime amendments may be necessary in acidic soils to adjust pH and enhance nutrient availability for optimal plant growth.

In summary, while there is no significant effect for the interaction between the three factors on soil lime content, the results clearly show that sandy loam soils have much higher lime content compared to clay soils. This disparity can be attributed to the geological history and parent materials of the soils. The higher lime content in sandy loam soils can have implications for soil pH and nutrient availability. Understanding lime content is crucial for effective soil management and making informed decisions regarding nutrient application and pH adjustment. The effect of treatments on soil lime content is given in Fig 4.28.

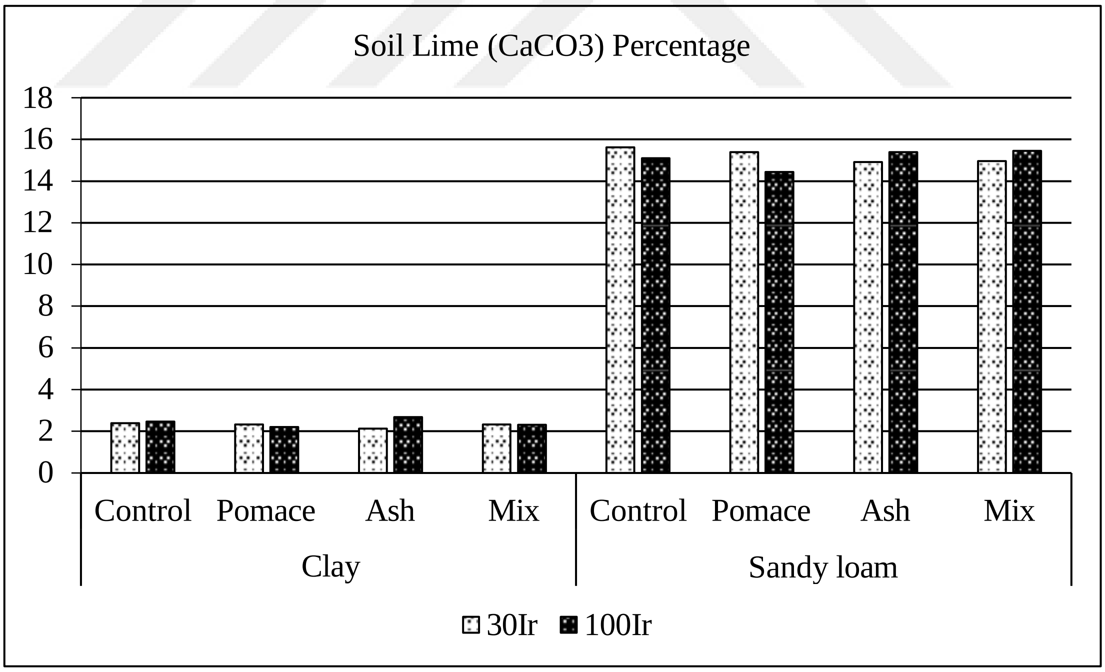

Figure 4.28. The effect of treatments on the soil lime ($CaCO_3$) Percentage.

4.3.7. Soil Exchangeable Sodium (Na) Content

The results examine the effects of the factors on soil exchangeable sodium (Na) content. While there is no significant effect for the interaction between the three factors, there is a significant difference based on soil type.

The results indicate that the sandy loam soil has higher levels of exchangeable sodium compared to the clay soil. This difference can be attributed to the inherent characteristics of the soils and their composition. Sandy loam soils typically have a coarser texture and larger pore spaces, which can lead to faster leaching and movement of ions, including sodium. As a result, sodium ions are more likely to be retained in the soil solution and are not effectively flushed out, leading to higher levels of exchangeable sodium.

On the other hand, clay soils have finer particles and smaller pore spaces, which can promote the retention and accumulation of sodium ions. The clay particles have a higher surface area and higher cation exchange capacity, allowing them to adsorb and hold onto sodium ions more effectively, resulting in higher levels of exchangeable sodium.

The application of OPBA in both soil types under the two irrigation percentages shows the highest levels of exchangeable sodium compared to the other application types and the control. OPBA can contain varying amounts of sodium, and when applied to the soil, it can contribute additional sodium to the soil exchange complex. This can lead to an increase in the exchangeable sodium levels, particularly in sandy loam soils where sodium ions are not effectively leached out.

It is important to manage soil exchangeable sodium levels as high sodium content can have detrimental effects on soil structure, nutrient availability, and plant growth. High levels of exchangeable sodium can lead to soil dispersion, decreased water infiltration, and hinder root development. Implementing management practices such as leaching with high-quality irrigation water, improving soil drainage, and using amendments like gypsum can help mitigate the negative impacts of exchangeable sodium.

According to a study conducted by Kukier et al. (2001), on the distribution of exchangeable cations in the profiles of soils amended with coal combustion fly ash, it was observed that amendment of fly ash alone had no significant effect on soil exchangeable sodium.

In summary, while there is no significant effect for the interaction between the three factors on soil exchangeable sodium content, the results clearly show higher levels of exchangeable sodium in sandy loam soils compared to clay soils. This disparity is attributed to the inherent characteristics of the soils, including their texture and pore spaces. The application of OPBA also contributes to increased exchangeable sodium levels, particularly in sandy loam soils. Managing exchangeable sodium levels is essential for maintaining soil health and promoting optimal plant growth. The effect of treatments on soil exchangeable sodium is given in Fig 4.29.

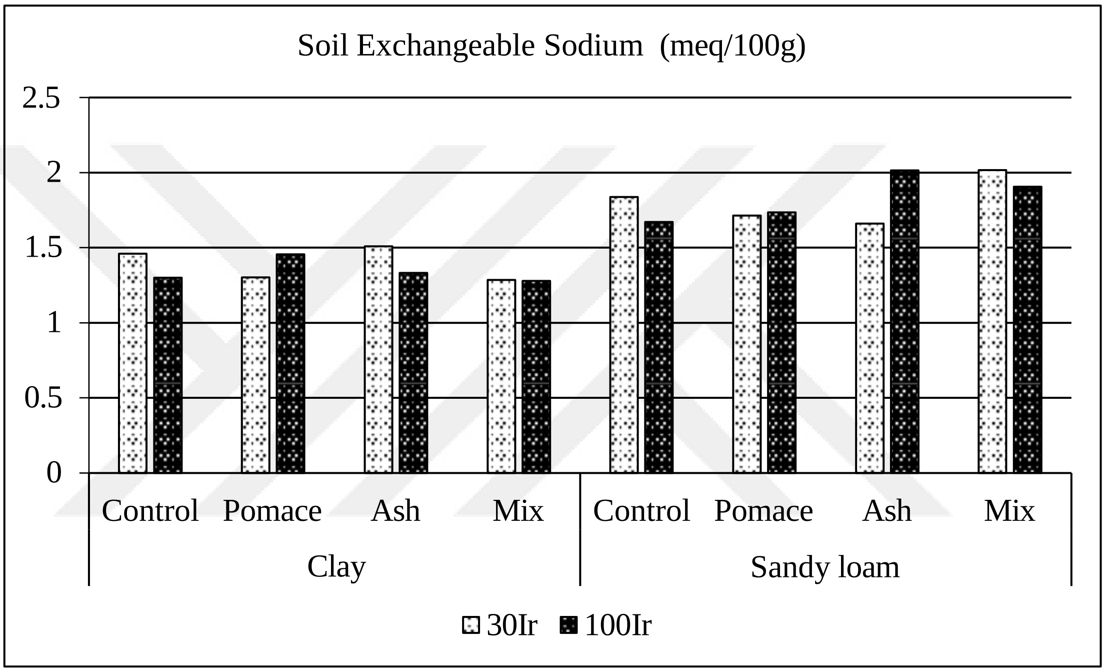

Figure 4.29. The effect of treatments on the soil exchangeable sodium (Na) content.

4.3.8. Soil Exchangeable Potassium (K) Content

The results indicate that the soil exchangeable potassium content is influenced by the soil type and application type, while the interaction of the three factors does not have a significant effect. The sandy loam soil exhibits a higher soil exchangeable potassium content compared to the clay soil. This suggests that the sandy loam soil has a naturally higher potassium availability or better retention of potassium compared to the clay soil.

Furthermore, the application types have a significant impact on the soil exchangeable potassium content. All types of application, including OP, OPBA, and OP+OPBA, result in an increase in soil exchangeable potassium in both soils.

Interestingly, the application types that include OP, such as the OP application and OP+OPBA application, tend to have a greater impact on increasing the soil exchangeable potassium content compared to the OPBA application. This implies that the organic matter content in OP may contribute to higher potassium availability in the soil.

The observed increase in soil exchangeable potassium content with the application types indicates that the added materials, such as OP, OPBA, and OP+OPBA, contribute to the enrichment of potassium in the soil. This can be attributed to the release of potassium from the applied materials, which enhances the overall soil fertility and nutrient availability for plant uptake.

According to a study conducted by Kukier et al. (2001), on the distribution of exchangeable cations in the profiles of soils amended with coal combustion fly ash, it was observed that amendment of fly ash alone had no significant effect on soil exchangeable potassium.

It is worth noting that the absence of significant interaction effects suggests that the individual factors (soil type, application type) play a more prominent role in influencing the soil exchangeable potassium content than their combined effects. These findings contribute to our understanding of the factors affecting potassium dynamics in soils and provide valuable insights for agricultural practices aimed at optimizing potassium availability and crop productivity. The effect of treatments on soil exchangeable potassium is given in Fig 4.30.

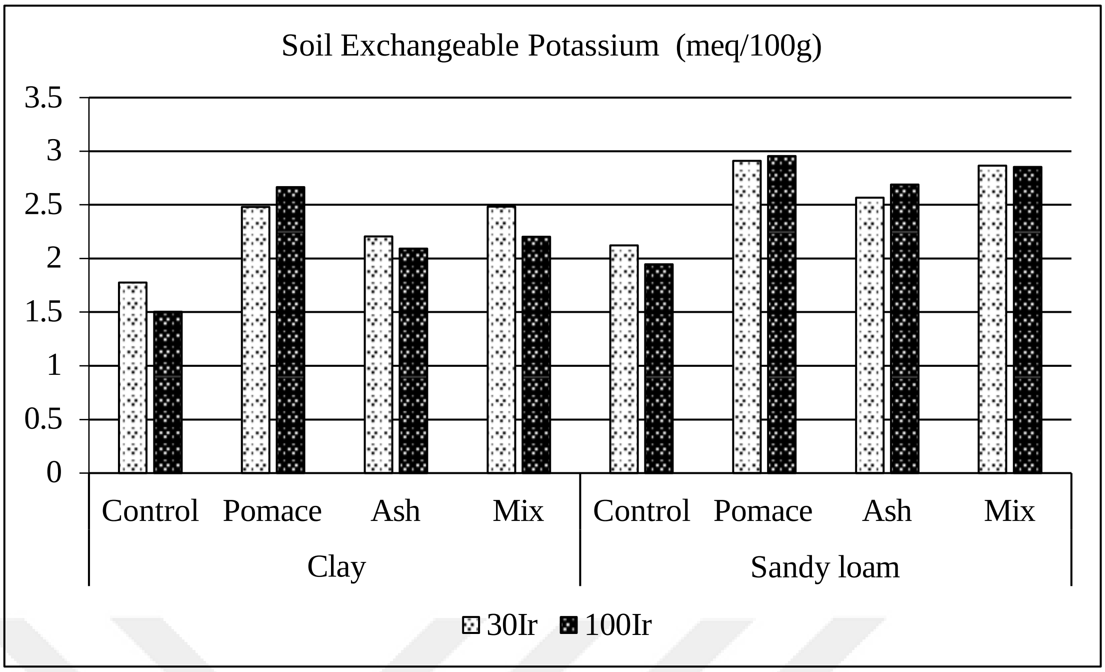

Figure 4.30. The effect of treatments on the soil exchangeable potassium (K) content.

4.3.9. Soil Exchangeable Calcium (Ca) Content

The results of the soil exchangeable calcium content indicate that there is no significant effect of the three factors' interaction. However, there is a significant effect of the soil type and application type on soil exchangeable calcium.

In terms of soil type, the clay soil exhibits higher levels of soil exchangeable calcium compared to the sandy loam soil. This suggests that clay soil has a greater natural abundance of calcium ions, which contributes to higher exchangeable calcium levels.

Regarding the application type, the findings reveal interesting trends. In the clay soil, the addition of OP slightly decreases the soil exchangeable calcium content. This implies that OP may have a binding effect on calcium ions, leading to a reduction in their availability in the soil. On the other hand, the application of OPBA and OP+OPBA to the clay soil slightly increases the soil exchangeable calcium content. This suggests that these application types may enhance the release or availability of calcium ions in the soil, leading to an increase in exchangeable calcium levels.

In the sandy loam soil, the application of OP and OPBA under 30% irrigation slightly increases the soil exchangeable calcium content compared to the 100% irrigation, which has no significant effect on the soil. This indicates that the addition of OP and OPBA, particularly under limited irrigation, can enhance the availability of calcium ions in the sandy loam soil. Additionally, the OP+OPBA application in sandy loam soil under both percentages of irrigation shows an increase in soil exchangeable calcium, suggesting that this specific application type promotes the release or availability of calcium ions in the soil.

According to a study conducted by Deenik et al. (2011) on the effect of charcoal ash on acid ultisols, it was observed that the application of charcoal ash significantly increased exchangeable calcium. While Kukier et al. (2001) observed that soils amended with fly ash had no statistically effect on exchangeable calcium.

Overall, the results highlight the importance of soil type and application type in influencing soil exchangeable calcium content. The differences observed can be attributed to variations in the inherent characteristics of the soil and the specific effects of the applied materials. Understanding these factors is crucial for managing soil fertility and optimizing calcium availability, as calcium plays a vital role in various plant functions and nutrient balance. The effect of treatments on soil exchangeable calcium is given in Fig 4.31.

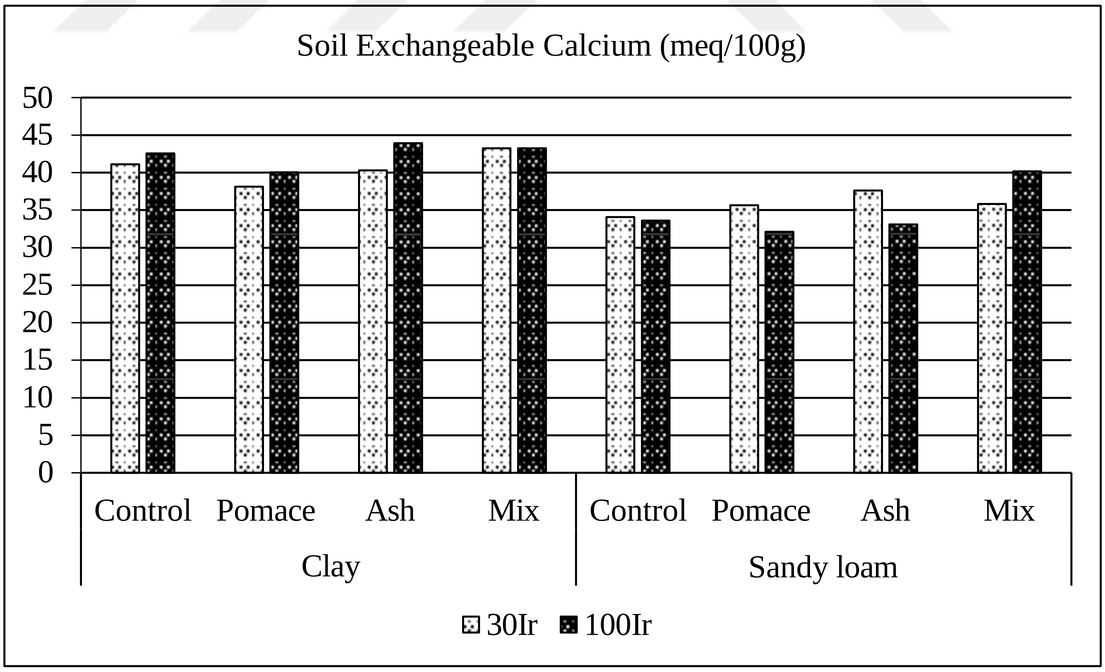

Figure 4.31. The effect of treatments on the soil exchangeable calcium (Ca) content.

4.3.10. Soil Exchangeable Magnesium (Mg) Content

The results indicate that there is no significant effect of the three factors' interaction on the soil exchangeable magnesium. However, there is a significant effect of the soil type, application type, and the interaction between irrigation and application type on the soil exchangeable magnesium.

In terms of soil type, the sandy loam soil shows higher levels of exchangeable magnesium compared to the clay soil. This suggests that sandy loam soil has a higher content of magnesium.

When considering the interaction between irrigation percentage and application type, in clay soil under 30% irrigation, all applications lead to a decrease in soil exchangeable magnesium compared to the 30% irrigation control. However, under 100% irrigation, the application of OP increases the exchangeable magnesium content, while the application of OPBA and OP+OPBA decreases it compared to the 100% irrigation control.

In sandy loam soil under 30% irrigation, applying OPBA shows similar levels of exchangeable magnesium as the control, while applying OP (in both OP and OP+OPBA applications) decreases the content of exchangeable magnesium. Under 100% irrigation, applying OP or OPBA increases the soil exchangeable magnesium compared to the 100% irrigation control, while applying OP+OPBA decreases it.

According to a study conducted by Deenik et al. (2011) on the effect of charcoal ash on acid ultisols, it was observed that the application of charcoal ash significantly increased exchangeable magnesium.

These findings suggest that the soil type and the specific application types have an impact on the soil exchangeable magnesium content, while the irrigation percentage does not have a significant effect. The effect of treatments on soil exchangeable magnesium is given in Fig 4.32.

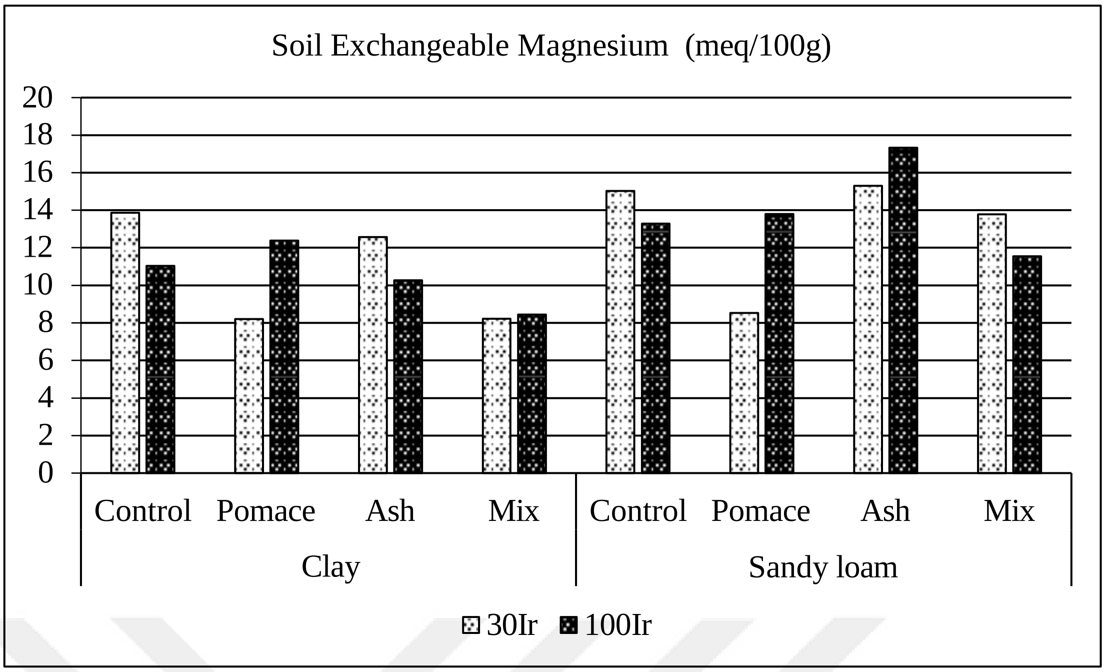

Figure 4.32. The effect of treatments on the soil exchangeable magnesium (Mg) content.

5. CONCLUSION

In conclusion, the comprehensive analysis of the effects of treatments on plant yield and soil properties provides valuable insights into the complex interactions between soil type, irrigation management, and application types. Sandy loam soil exhibits lower plant yield due to its inherent characteristics, such as lower water-holding capacity and nutrient retention. Higher irrigation levels contribute to improved plant yield in both soil types, emphasizing the importance of efficient water management. The choice of application type significantly influences plant yield, with the OP+OPBA application consistently demonstrating the highest yield, indicating its positive impact on nutrient availability and overall plant growth. OP application also shows positive effects, while the results of OPBA application vary depending on soil type. These findings underscore the importance of considering soil type and implementing appropriate management practices, such as irrigation and tailored application types, to maximize plant yield and promote sustainable agriculture.

Furthermore, the analysis of soil physical properties highlights the significance of soil type and management practices in shaping soil structure and function. Sandy loam soil generally exhibits higher bulk density and dispersion ratio, while clay soil showcases improved porosity, aggregate stability, structure stability index, and water-holding capacity. Lower irrigation levels contribute to slightly increased bulk density and reduced porosity in both soil types. The OP+OPBA application consistently demonstrates favorable outcomes in terms of reducing bulk density, increasing porosity, enhancing aggregate stability, and improving structure stability index. OP application positively impacts porosity and aggregate stability, while OPBA application displays diverse effects based on soil type. These findings underscore the importance of considering soil type and implementing appropriate management practices to optimize soil physical properties and promote sustainable agricultural practices.

In conclusion, the analysis of various soil chemical properties sheds light on the effects of treatments on crucial soil parameters. The application type plays a significant role in determining soil pH, with OPBA application resulting in a more alkaline environment, while OP and OP+OPBA applications exhibit slightly lower pH values compared to the control. Sandy loam soil demonstrates slightly higher electrical conductivity (EC) compared to clay soil, and the OP, OPBA, and OP+OPBA applications increase EC levels in both soil types. Sandy loam soil exhibits higher organic matter content, with the OP application yielding the highest levels. Available phosphorus content is higher in sandy loam soil and influenced by soil type, irrigation percentage, and application type. Cation exchange capacity is higher in clay soil and slightly increased by the application of OP, OPBA, and OP+OPBA. Lime content is higher in sandy loam soil, while exchangeable sodium content is higher in sandy loam soil and can be increased through OPBA application. Exchangeable potassium content is higher in sandy loam soil and can be increased by the application of OP, OPBA, and OP+OPBA. Exchangeable calcium content is higher in clay soil and can be slightly increased by OPBA and OP+OPBA application. Exchangeable magnesium content is higher in sandy loam soil and influenced by the interaction between irrigation percentage and application type. Understanding these effects is crucial for soil management, optimizing nutrient availability, and promoting plant growth and productivity in a sustainable manner.

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CURRICULUM VITAE

Sinan Abu Al Hayja graduated from Jordan University of Science and Technology with a B.Sc degree in Soil and Irrigation in 2020. During this period he got a grant to cover an exchange mobility for one semester in Agricultural University of Plovdiv, BULGARIA Issued by ERASMUS+ with the support of European Union (Feb 2019- Aug 2019). In 2021, he enrolled in a joint master degree program ‘’Erasmus Mundus Joint Master’s Degree in Soil Science (emiSS)’’ and studied in 2 universities, Ondokuz Mayıs University, Samsun, Turkey, and University of Agriculture in Krakow, Poland.

Contact Information :

ORCID ID : 0000-0003-2396-4737

Publications :

1. Al Hayja, S. A., Gülser, C., & Azab, M. (2022). Potential of using fly ash as amendment for soil characteristics. International Soil Science Symposium on “Soıl Scıence and Plant Nutrıtıon” 2 – 3 December 2022, Samsun, Türkiye, Book of Proceedings, pp.154-159.

2. Azab, M., Kizilkaya, R., Al Hayja, S.A. (2022). Possibility of using vermicompost to improve oil plants productivity. International Soil Science Symposium on “Soıl Scıence and Plant Nutrıtıon” 2 – 3 December 2022, Samsun, Türkiye, Book of Proceedings, pp.60-63.

Won Awards, Incentives and Scholarships

1. Erasmus Mundus Joint Master Degree Scholarship.
2. Erasmus+ Exchange Mobility.