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A Brief Discovery on the Evaluation of Rock Wool and Zeolite in a Hydroponic Drip System for The Cultivation of Lettuce (Lactuca Sativa)

Norsuhailizah Sazali[1*], Mohd Syafiq Masduqi Mohd Zainudin[2], Ashmal Abid Mohamad Radzi[2], Muhammad 'Ali Hashim[2], Muhammad Lutfi Mohd Rizal[2], and Desmarita Leni[3]

[1]Faculty of Mechanical Engineering & Technology, UniMAP, 02600 Arau, Perlis, Malaysia.

[2]Department of Agrotechnology and Bio-Industry, Polytechnic Jeli Kelantan, Kelantan, Malaysia.

[3]Mechanical of Engineering, Universitas Muhammadiyah Sumatera Barat.

*Corresponding Author email: norsuhailizah@unimap.edu.my

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ABSTRACT
There is a growing interest in the utilization of soilless media, such as zeolite and rockwool, for cultivating vegetables in drip hydroponic systems. The motivation behind the selection of zeolite was due to its high cation exchange capacity (CEC) and ability to retain moisture. A study was conducted to determine the impact of zeolite and rockwool on the growth and leaching analysis of lettuce in a drip hydroponic system. The lettuce obtained fertilization through a nutrient solution that contains both macro and micronutrients. The solution's electrical conductivity (EC) ranged from 1.2 to 1.9 dS/m, with a pH of 5.75 and a temperature of 30-32 ºC. Based on the study on lettuce growth, an additional amount of zeolite in the rockwool system resulted in an increase of 11.48% in stem diameter, 5.13% in root weight, 25.5% in dry root weight, 20% in shoot weight, and 20.23% in dry shoot weight, as compared to rockwool only. However, there were no changes in lettuce height and leaf diameter identified. Based on the analysis of the hydroponic wastewater solution, the concentration of nitrate, nitrite, and ammonia ions decreased by 41.17%, 50%, and 75%, respectively, in the presence of zeolite in rockwool system compared to rockwool only. The presence of zeolite has a significant impact on reducing the concentration of nitrate, nitrite, and ammonia ions, however, it has a minimal effect on the growth of lettuce's height and leaf diameter.

1.0 Introduction

The world's population is growing at a fast pace and is projected to reach approximately 9.7 billion by 2050 (United Nations, 2014). Therefore, it is projected that a 70% increase in food production will be necessary to adequately feed this expanding population (Silva, 2018). To fulfill the growing food and feed requirements of the expanding population, it is crucial to employ creative methods to increase the availability of fresh produce worldwide (Pascual et al., 2018). This can be achieved by the utilization of advanced techniques in plant cultivation such as plant setting position i.e. lateral branch/node (Nik Yusof, Ontok, and Md Isa, 2024) and material technology. Lettuce, scientifically known as Lactuca sativa L., is well recognized as a highly favored leafy vegetable for its freshness and is classified within the Asteraceae family. Lettuce contains a high amount of fibre (Khodijah et al., 2021) and is a valuable source of vitamins (A, C, Iron, K, and folate) (Mulabagal et al., 2010; Kim et al., 2016), nutrients, minerals, and antioxidants (quercetin, caffeic acid, and lactupicrin) (Chiesa et al., 2009) that have positive effects on human health.

Lettuce is the predominant vegetable cultivated in hydroponic systems, which does not need soil. Studies have demonstrated that lettuce grown in this method has a high yield and is of excellent quality. Hydroponics is widely considered to be one of the most significant methods of soilless cultivation (Fussy & Papenbrock, 2022; Savvas et al., 2004). Hydroponic systems involve growing plants in direct contact with a nutrient solution that contains all the necessary macronutrients (N, P, K, S, Ca, Mg) and micronutrients (Fe, Zn, Mn, Cu, B, Mo, Cl) for plant growth (Resh, 2013). Hydroponics has little role in the overall world agricultural production, but it is widely used for growing high-value vegetable and fruit crops like lettuce, tomatoes, and herbs. They are also used for cultivating non-edible crops like flowers (Asao, 2012). The combination of greenhouse agriculture and the capacity to control nutrient availability in hydroponic systems results in much greater yields compared to soil-based systems (Barbosa et al., 2015; Kürklü et al., 2018). The extensive utilization of chemical fertilizers and pesticides in agriculture to improve crop yields and animal standards presents a substantial risk to surface and groundwater (United Nations Summary Progress Update, 2021).

Wastewater hydroponics utilizes the nutrients found in wastewater as vital components for the development of plants. The nutrient solutions must contain substantial quantities of macro elements, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S), together with small amounts of microelements, such as iron (Fe), boron (B), manganese (Mn), zinc (Zn), and copper (Cu). Based on Taiz et al., (Taiz et al., 2013), these crucial components are categorized according to their respective quantities in plant tissues, with the hierarchy being N > K > Ca > Mg > P > S > Fe > B > Mn > Zn > Cu. Insufficient nutrients in the wastewater can impede crop growth. Research has shown that using treated wastewater to irrigate crops can result in a decrease in crop production of about 50% when compared to using commercial nutrient solutions. This is due to the amount of nutrient content in the wastewater being low (Boyden & Rababah, 1996; Krishnasamy et al., 2012). An enclosed hydroponic system, also known as a continuous flow solution culture, can conserve a greater amount of water and fertilizers compared to an open system. For instance, a high pH level causes an increase in the formation of calcium and magnesium precipitates, while reducing the solubility of iron and phosphate in the nutrient solution. This results in the formation of ions that are unavailable for root absorption, thereby inhibiting the uptake of micronutrients like iron, copper, zinc, and manganese (Singh et al., 2019; Gillespie et al., 2020). In contrast, a low pH reduces the uptake of macronutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium (Velazquez-Gonzalez et al., 2022).

Rockwool is an artificial growth medium that replicates the activities of soil but is essentially free from any living organisms before planting (De Rijck, et al., 1998; Vallance, et al. 2011). Similar to loamy soil, it possesses a remarkable ability to absorb and retain water, while also having air pores for roots (De Rijck & Schrevens E. 1998; Alsanius & Wohanka, 2019). In contrast to soil, it lacks chemical reactivity, allowing for precise regulation of nutrients delivered to the roots through the irrigation system (De Rijck & Schrevens, 1998; Alsanius, Wohanka, 2019). Throughout the day, the rockwool is consistently watered with a solution containing all the necessary nutrients for plants (fertigation). It is then allowed to drain, resulting in a continuous flow of solution through the medium. Rockwool provides a highly uniform environment, in contrast to soil, which contains a diverse range of mineral and organic particles with varying surface features, as well as grains and aggregates of different sizes and textures, and a vast variety of soluble chemicals (Alsanius & Wohanka, 2019). Rockwool is a type of insulation material made from rocks and minerals. Rockwool is frequently utilized as a growing medium in hydroponic systems. The material in question is manufactured through the process of melting rock and subsequently spinning it into fibers. This substance's flexibility and accessibility render it appropriate for a wide range of plant species (Bridget White, 2004).

Various reports have been published regarding the utilization of zeolite and perlite as substrates in hydroponic cultivation (Maloupa et al., 1999). Zeolites are crystalline alumina silicates with a negative charge, which is counterbalanced by one or two positively charged cations with a valence of 30. Zeolites possess several additional qualities, including a high absorption capacity, the ability to hold and release water, a high cation exchange capacity (CEC), and a strong buffering capacity against changes in pH (Allen &D.W. Ming, 1995). The zeolites' significant trait of having a high capability for exchanging cations NH4+ and K+ has been recognized as vital (Maloupa et al., 1999). Zeolite's high cation exchange capacity (CEC) and ability to retain water and nutrients result in enhanced crop output and fruit quality (Djedidi et al., 1997). Zeolite enhances plant growth by mitigating nitrogen leaching in the soil (Thakulla et al., 2021). Zeolite is rich in essential elements, including Calcium (Ca), Potassium (K), and Magnesium (Mg) (Abdel-Mawgoud et al., 2006). Zeolite functions by prolonging the binding of nutrients before their absorption by plant roots. Its application in agriculture, particularly for crops, aids in the absorption of nutrients in the soil, followed by their distribution throughout all sections of the plant. Zeolite aids in the prevention of nitrogen loss in the soil and facilitates the process of plant growth (Cataldo et al., 2021). The primary objective of the study is to examine the impact of zeolite added to rock wool on enhancing plant growth (plant height, stem diameter, leaves diameter, shoot weight, dry shoot weight, root weight, dry root weight) and decreasing the levels of nitrate, nitrite, and ammonia in hydroponic effluent.

2.0 Material and Method

2.1 Hydroponic Design

Two hydroponic systems were designed to compare the effects of plant growth and wastewater in hydroponic systems with and without zeolite. Each system was equipped with one water pump and ten pots of lettuce. The water pump successfully circulated a volume of 120 liters within the tank. The dimensions of the design are 25 cm in width, 50 cm in height, and 50 cm in length. The primary materials utilized in the design and construction of the drip hydroponic system were PVC pipe, PVC glue, a 3mm microtube, a dripper, a plastic tank, a water pump, and a timer. Figure 1 depicts the hydroponic drip system utilized in the experiment.

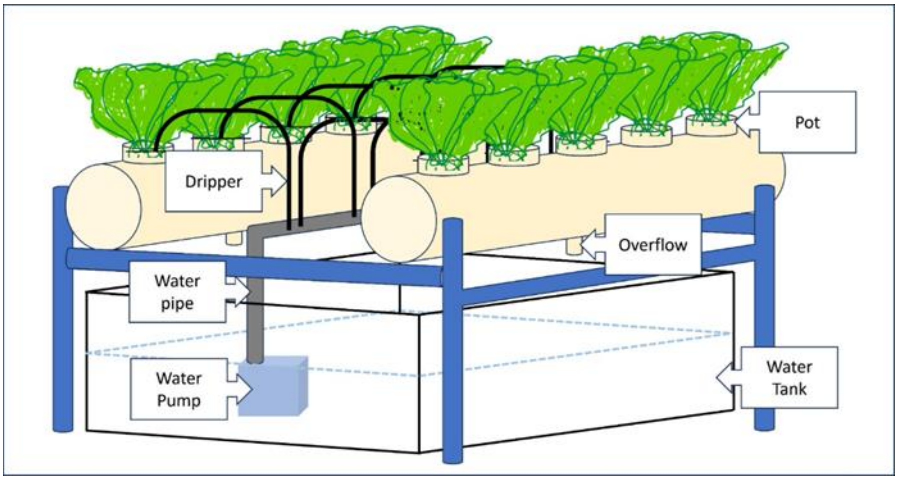

Figure 1: Design of Hydroponic Drip System

2.2 Plant Material and Other Material

The experiment utilized lettuce seeds from the Leckat GWG 633 variety. The experiment utilized rockwool and zeolite as the growing media. Rockwool is a substance made from two natural components, basalt rock and chalk, which are subjected to extreme heat of 3000 degrees Fahrenheit. The heated mixture is then spun and cooled, resulting in a material that is highly suitable for the root zone of plants. Rockwool lacks inherent nutrients; hence the plant relies entirely on the fertiliser solution provided. The zeolite consists of 71% SiO2, 11% Al2O3, and additional elements like FeO3, TiO3, CaO, and MgO. The AB fertilizer originated from Albar Farm and had an electrical conductivity (EC) reading of 1.0 dS/m for growth and 1.6 dS/m for enlargement. The Digital TDS meter was used to measure the electrical conductivity (EC), temperature, and total dissolved solids (TDS).

2.3 Experiment Design and Treatment

The experiment was carried out in a greenhouse at Politeknik Jeli Kelantan (PJK). 3 grams of rock wool were measured and placed in each pot of the hydroponic system with the other set of hydroponic systems filled with 2 grams of zeolite. Regular monitoring was conducted to ensure the upkeep of the plants. The lettuce seedlings were directly transplanted into a hydroponic system, and a nutrient solution was applied after 5 weeks. The plant was irrigated at a rate of 40 ml per day for each drip system. The crop was then harvested 36 days after being sown.

2.4 Data Collection

Measurements were obtained for leaf diameter, plant height, number of leaves, stem diameter, shoot weight, root weight, weight of dry shoot, and weight of dry root for each plant. The outcome was assessed by computing the mean of each plant's growth attributes and concentration of wastewater from the hydroponic system (nitrate, nitrite, ammonia). The data was entered into Microsoft Excel to calculate precise means for plant growth analysis and leaching analysis based on the collected data.

3.0 Result And Discussion

3.1 Plant Growth Analysis

Figure 2 illustrates the mean comparison of lettuce height, stem diameter, and leaf diameter between additional zeolite in rockwool and rockwool only in a hydroponic drip system. Meanwhile, Figure 3 displays the mean comparison of shoot weight, dry shoot weight, root weight, and dry root weight between additional zeolite in rockwool and rockwool only in the drip hydroponic system. Based on Figure 2, the addition of zeolite in rockwool shows a 6.6% decrease in the lettuce height compared to the system using rockwool only. However, the addition of zeolite in rockwool results in an 11.48% increase in stem diameter compared to using rockwool only in hydroponic systems. Both treatments give the same value of pH, 5.57 but slightly different temperatures for rockwool (30.28 ºC) and rockwool + zeolite (32 ºC). The temperature of water can impact various physiological processes that occur during the growth and development of plants. The absence of bio-stability can lead to significant volume reduction, compaction, decreased air volume, increased water availability, and porosity due to mineralization. Additionally, there may be alterations in the composition of the gaseous phase due to the formation of carbon dioxide. These modifications have the potential to ultimately decrease the rate of plant development.

Figure 3 demonstrates that the addition of zeolite in rockwool results in significantly greater mean weights of shoot, root, dry shoot, and dry root, in comparison to using rockwool only. When comparing the percentage of the difference between additional zeolite in rockwool and rockwool only, additional zeolite in rockwool shows a higher percentage difference for shoot weight (20%), dry shoot weight (20.23%), root weight (5.13%), and dry root weight (25.5%) compared to the rockwool only in drip hydroponic system. Rahman et al. (2017b) (Rahman et al., 2017) found that the weight of lettuce rose as the amount of nutrition provided increased. According to Michael and Lieth (2008) (Michael & Lieth, 2008), an increase in total pore space often leads to a decrease in water retention, along with an increase in oxygen transport, and an increase in root penetration. These factors, in turn, will have an impact on the growth of plants.

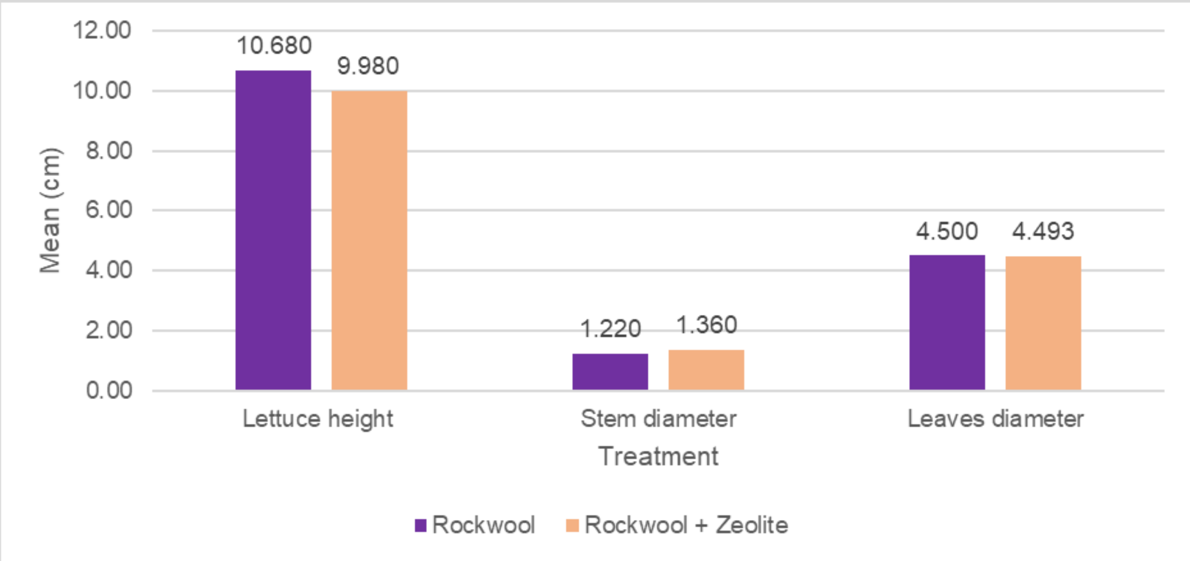

Figure 2: The Mean Comparison of Lettuce Height, Stem Diameter, and Leaves Diameter Between Rockwool and Rockwool + Zeolite

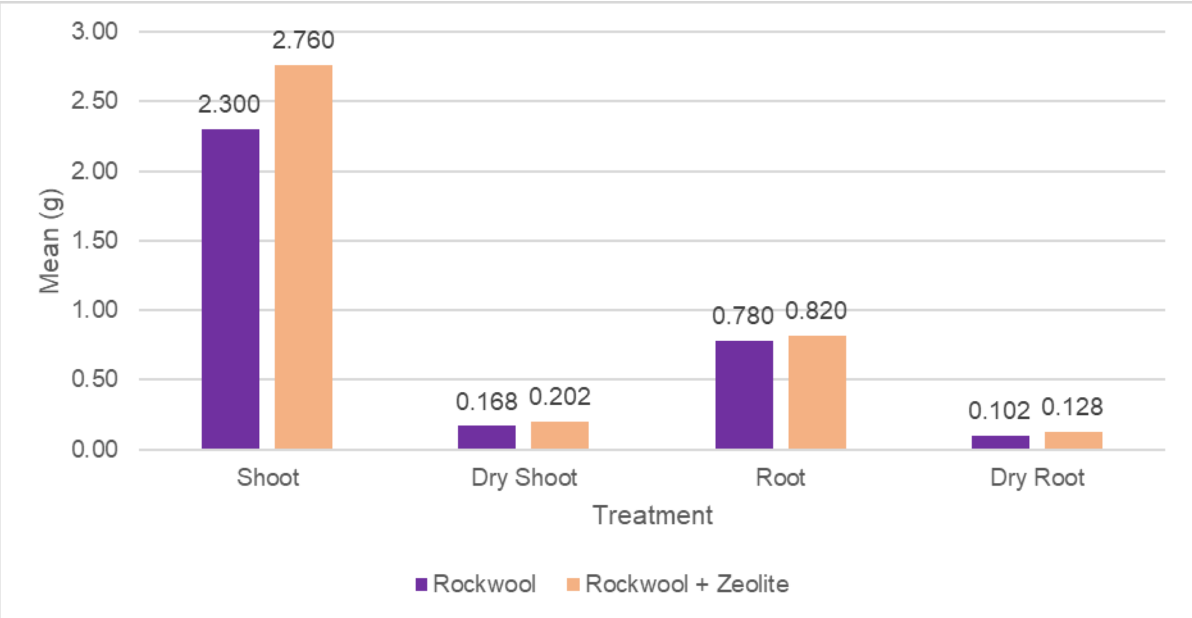

Figure 3: The Mean Comparison of Weight of Shoot, Weight of Dry Shoot, Weight of Root, and Weight of Dry Root Between Rockwool and Rockwool + Zeolite

3.2 Leaching Analysis

Based on Figure 4, a decrease in the mean concentration of nitrate, nitrite, and ammonia was observed from the system utilizing zeolite in a hydroponic drip system. The hydroponic wastewater solution analysis showed that the zeolite + rockwool system resulted in a reduction of 41.17% in nitrate concentration, 50% in nitrite concentration, and 75% in ammonia ion concentration, compared to a system using the rockwool only. The EC reading of rockwool+zeolite gives a higher value, 1.65 dS/m compared to rockwool only, 1.62 dS/m. According to reports, utilizing zeolite has an aluminosilicate cage structure that has a stronger attraction for NH4+ compared to other cations such as Na+, Ca2+, and Mg2+ ions [38, 39]. The exceptional specificity of zeolite for NH4+ ions is achieved through a combination of ion exchange and adsorption mechanisms, which are influenced by the molecular size characteristics, hydration of the cation, and the separation between anionic corners (Si/Al ratio) of the zeolite. The process of removing ammonium with zeolite was suggested to involve monolayer molecule adsorption with zeolite (Lin et al., 2014).

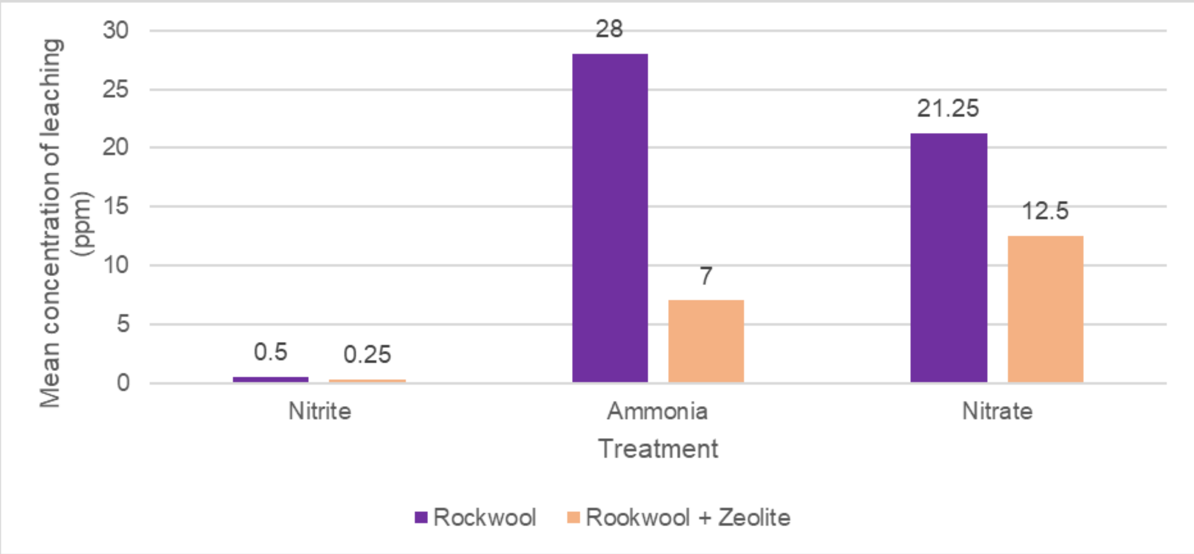

Figure 4: The Mean Concentration of Nitrite, Nitrate, and Ammonia for Rockwool and Rockwool + Zeolite

4.0 Conclusion

From the presented data, the addition of zeolite in the rockwool enhanced the lettuce growth in its stem diameter, yet had minimal effect on the height of the lettuce and leaf diameter. Moreover, the weight of the lettuce shoot, dry shoot, root, and dry root in the system integrating zeolite was slightly higher than the system utilizing rockwool only. Additionally, the presence of zeolite in the system reduces the concentration of nitrite, nitrate, and ammonia in the hydroponic wastewater. This discovery has provided the possibility of utilizing zeolite in hydroponic systems to decrease the concentration levels of nitrate, nitrite, and ammonia, and promote plant development. In summary, zeolite has a high cation exchange capacity and serves as a good adsorbent that can retain water and minerals for enhancing lettuce growth and quality.

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Author Contributions

Norsuhailizah S.: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data curation, Writing- Original Draft Preparation, Writing – Review & Editing, Visualisation, Supervision, Project Administration, Funding Acquisition; **Mohd Syafiq Masduqi M. Z.**: Validation, Writing – Review & Editing; **Ashmal Abid M. R.**: Formal Analysis, Investigation, Resources, Data Curation, Visualisation, Funding Acquisition; **Muhammad 'A. H.**: Software, Investigation, Resources, Data Curation, Visualisation, Funding Acquisition; **Muhammad Lutfi M. R.**: Data Curation, Resources, Visualization, Funding Acquisition; and **Desmarita L.**: Resources.

Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its Submission, and declare no conflict of interest in the manuscript.

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