TROPICAL LIFE SCIENCES RESEARCH

Morpho-Physiological Responses of Selected Vegetables in Hydroponic and Soil-Based Systems Under Climatic Stress

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Highlights

- Hydroponics enhanced nutrient-use efficiency with superior Zn, Fe, and Cl^- uptake.
- Significant improvement in morpho-physiological traits observed in Okra, Chili, and Eggplant.
- Hydroponics maximized yield, resource-use efficiency, and minimized environmental footprint.

EARLY VIEW

Morpho-Physiological Responses of Selected Vegetables in Hydroponic and Soil-Based Systems Under Climatic Stress

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Running head: Morpho-Physiological Responses

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Abstract: An extreme climatic change due to anthropogenic activities causes disruptions in ecosystems and threatens the planet's overall balance. Hydroponic is smart and sustainable agriculture practice that aims to produce two times more yield than traditional practices. To investigate the efficiency of hydroponics technique, the morpho-physiological responses of selected vegetable species were analyzed. Tomato *(S lycopersicum L.),* Eggplant *(S melongena),* Lettuce *(L sativa),* Green Chili *(C Annuum)* and Okra *(A esculentus)* were selected for the experiment. Soil nutrients analysis and hydroponics nutrients uptake analysis were also carried out side by side using UV-Visible Spectroscopy, Atomic Absorption Spectroscopy and Titration method. In hydroponic water analysis, it was found that 42% of supplied Cl^- had been taken up by the plants whereas 79% of all supplied Zinc and Iron had been taken up by the plants. The uptake percentages of other anions and cations ranged between 45% to 62%. Morpho-physiological responses of Lettuce and Tomato in soil-based and hydroponic experiments were almost similar. Whereas, hydroponically grown Okra, Green Chili and Eggplant showed maximum height, roots length, number of leaves and weight. Overall findings showed that hydroponic system was more efficient in terms of crops yield, water usage and environmental contamination. Thus, it is recommended to increase the duration of experiment in future to further verify the climatic change effects.

Keywords: Climate Change, Food Insecurity, Hydroponic System, Morpho-Physiological Response, Soil Nutrient Analysis, Crop Yield Improvement

INTRODUCTION

Agriculture as a multidisciplinary approach encompasses both arts and science, involves the cultivation of crops and growing livestock. Despite advancements in agricultural technology, traditional farming methods persist globally, exacerbating soil degradation. Pakistan is one of the developing countries and the agricultural sector is considered as its economy's backbone. To meet the food demand of this increasing population under climatic stresses, rapid urbanization and deforestation; farmers are under great burden to produce maximum quantities of crops at a faster rate. For this, farmers use different types of chemical fertilizers and pesticides extensively to enhance crop yields and protect them from pests' attacks. This use of fertilizer/pesticides is affecting soil fertility too (Khan, et al., 2018). Climatic changes such as sudden fluctuations in rainfall, humidity, temperature and weather patterns pose a great effect on many crops of Pakistan such as Wheat, maize, corn rice, mint saffron, etc. (Alsamir, et al., 2017). Furthermore, ethnobotanical surveys conducted in Pakistan have documented that several plant species function dually as food and sources of therapeutic agents within indigenous healthcare systems (Adnan, et al. 2014; Tariq, et al., 2015; Tariq, et al., 2016). This multifunctionality underscores the significance when evaluating alternative cultivation approaches, such as hydroponic production under climatic stress conditions. Hydroponic system or hydroponics is one of the advanced sustainable agricultural techniques that produces 2-3 times higher yield and eliminates the use of other inert mediums like soil, sand and gravel, thus protecting soil from contamination and infertility. Hydroponics is the type of hydroculture in which crops or a plant grows entirely in water. This system can grow any type of plant as the roots of plants are completely exposed to nutrient rich solutions containing all the essential micro and macronutrients taken up by plants through soil (Son, et al., 2020). There are more than 50 different types of hydroponic systems being used in the world. Although all these systems perform the same functions, the difference is in the arrangement of physical components of the system. Physiological responses due to nutrients conc. altered the leaf, root and shoot morphology along with affecting chlorophyll content and evapotranspiration rate. However, the study by Kamble et al. (2013) suggested that soil tests could also be used to analyse the relationship between each soil nutrient with the pH. Research conducted by Soodan et al. (2014) highlighted different analytical techniques that are used for soil analysis including UV-Visible Spectroscopy, Atomic Absorption Spectroscopy, Fourier Transform Infrared Spectroscopy. Previous studies highlighted the fact that increase in concentration of copper in hydroponic nutrient solution or in the soil (added artificially through fertilizers) also affects the growth and various other factors of plants. Therefore, the aim of present study is to investigate the efficiency of hydroponics technique, the morpho-physiological responses of selected vegetable species performed. Moreover, the soil nutrients analysis and hydroponics nutrients uptake analysis were also carried out by using UV-Visible Spectroscopy, Atomic Absorption Spectroscopy and Titration method.

MATERIALS AND METHOD

Study Area

The area selected for study was Fatima Jinnah Women University, Rawalpindi, Pakistan located at 33^{o} 35'10″ N 73 ^{o} 03' 54″ E. The experiments were conducted in spring and summer seasons i.e. start of May, 2023 to end of June, 2023 at the greenhouse of the Environmental Sciences Department, Jinnah Women University, Rawalpindi, Pakistan. Five seasonal vegetables were selected to study and contrast the morpho-physiological changes of hydroponic vegetables with those grown in the soil.

Vegetable Species Selected for the Study

Total 30 plants (6 from each species) were germinated and used for the experiment. Out of those six, three were used for soil-based experiments and three were used for Hydroponics experiments. Tomato *(Solanum lycopersicum L.),* Eggplant *(Solanum melongena),* Lettuce *(Lactuca sativa),* Green Chili *(Capsicum Annuum)* and Okra *(Abelmoschus esculentus)* were the vegetable species selected for the experiment because all these grow efficiently in warmer season between temperature 25-32 ^{o}C. The experiment was carried out for 60 days. Total of 20 different healthy seeds of each vegetable mentioned above were sown in different germination mediums with the help of spatula. As for the soil based experiment, a mixture of compost and soil present in the greenhouse of the university was used. The soil was loamy, sandy and silty. No additional fertilizers were added to the soil till end of the experiment. Soil was plowed and levelled before the transfer of seedlings into it. The soil medium plants were irrigated two times daily respectively at 9:00 a.m. and 3:30 a.m.

Hydroponic Setup

In this experiment, a Deep Water Culture (DWC) hydroponic system was designed in a greenhouse. Instead of using distilled/filtered water we have used tap water with a pH between 7.5-8. No additional chemical was added to adjust the pH range of the water. As for the loss of water due to evaporation, additional 10-12 liters of water was added to the container before every change (in between periods of every 2 weeks) without the addition of nutrient solution. No EC (Electrical Conductivity) was maintained during the experiment. Experimental setup consisted of 5 PVC (Poly Vinyl Chloride) pipes. Each measuring 5ft and 4 inches in length equipped with four holes at regular intervals along the length. These pipes were interconnected to form a “U” shaped structure with a slope. Setup also consisted of one plastic container capable of holding 55-60 liters of nutrient rich hydroponic solution (Figure 1). A mini water pump was used to circulate nutrient rich solution from the container to the PVC pipe. The water moved with the slope and drain into the same container circulating again and again. The roots of selected vegetable were exposed completely to the nutrient rich solution throughout the study. In an endeavor to minimize environmental impact and optimize resource utilization, plastic bottles were reused by cutting into half and adding foam to give support to the plant's stem. Hydroponic solution was changed after every two weeks. Discarded water was mixed with tap water and reused for watering other plants located near to the greenhouse to avoid wastage of water (Shrestha & Dunn, 2010). The concentrations of all the chemicals used in 100 liters of water are given in Table 1.

Figure 1: The study's experimental set in greenhouse.

Table 1: Concentration of Laboratory chemicals used in hydroponic system per 100 L of water (Mattson, 2018).

Solution "A" Chemicals	Percentage (%)	Solution "B" Chemicals	Percentage (%)
Calcium Nitrate	26.6	Iron Chloride	0.27
Magnesium Sulfate	26.6	Manganese Sulfate	0.05
Mono Ammonium Phosphate	5.3	Zinc Chloride	0.05
Mono Potassium Phosphate	6.39	Copper Sulfate	0.03
Potassium Nitrate	7.99	Boric Acid	0.03
Potassium Sulfate	26.6	Sodium Molybdate	0.005

Soil Sample Preparation

Wet digestion process was carried out step by step for each soil sample respectively. Prepared Aqua Regia 3:1 HNO_3 to HCL. 176.25ml HNO_3 was added in 56.25ml HCL collectively for all 15 samples. Used 11.25ml HNO_3 and 3.75ml HCL for each sample. Total of 1g soil sample and the Aqua regia was then added into a 250ml beaker. Beaker was placed over the hotplate at 70^{o}C for 40 minutes. Waited till the solution became transparent. Sample was passed through Whatman Filter paper no. 42. Deionized water was added to the sample to make 50 ml volume in the falcon tube (Maurya, et al., 2018).

Water Sample Preparation

In this study a total of 20 water samples from hydroponic solution were collected. Total 2 samples at the start of each hydroponic solution (water) changing event and 2 after the interval of one week. During the experiment hydroponic nutrient rich water was changed five times. Samples were just filtered with Whatman Filter Paper no. 42 to remove impurities.

Nutrients Analysis by UV-Visible Spectroscopy

Copper, Zinc, Manganese, Iron, Magnesium, Calcium and Potassium was analyzed using AAS (Atomic Absorption Spectroscopy). Nitrogen, Phosphorus, sulfur and Boron were analyzed using UV-Visible spectroscopy, chloride by using titration method as per previously reported methods. (Mussa, et al., 2009; Jagessar & Sooknundun, 2011; Estefan, 2013).

RESULTS AND DISCUSSION

The results obtained shows the different parameters of plants, soil and hydroponic system that have been investigated with the aim to provide insights on the role these factors, play in promoting significant plant growth and establishing a sustainable hydroponic system.

Moisture Content and pH of Soil and Water Sample

Findings revealed the percentage moisture content range of 11% - 19% in studied soil samples. Average moisture content observed in soil samples was 15.6%. This parameter is responsible for soil microbial and fungal activities. Investigation recorded pH levels within a range of 7.1 to 8.0 for soil samples and 7.0 to 8.0 for water samples.

Soil and Hydroponic Nutrients Analysis

Soil analysis

The study involved the analysis of concentrations of different anions and cations in soil samples using various methods and analytical techniques. Concentrations of these elements individually affect the growth and development of plants. For experimentation, five different soil samples denoted as S1, S2, S3, S4 and S5 were used for the cultivation of soil based plants, namely

Tomato, Green Chili, Okra, Lettuce and Eggplant, respectively. The average concentrations of Potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Chloride (Cl), Nitrate, Phosphate, Sulfate and Boron observed in soil samples were 147mg/kg, 2500mg/kg, 470mg/kg, 10mg/kg, 188mg/kg, 83mg/kg, 25mg/kg, 87mg/kg, 1.7mg/kg, 0.11mg/kg, 16mg/kg and 2.8mg/kg respectively as shown in Figure 2(a-d). The Concentration of K, Mg, Mn, Zn and Cl^- measured in soil samples (Figure 2a). The concentration of nitrates and sulfates measured in soil samples shown in Figure 2b and concentration of Iron, Copper, Phosphate and Boron measured in soil samples (Figure 2c) However, the Concentration of Calcium measured in soil samples represented in Figure 2d.

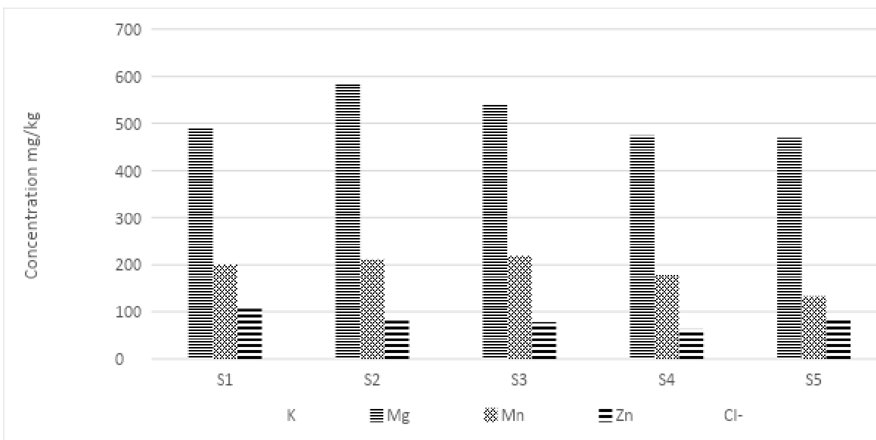

Figure 2a. Concentrations of potassium (K), magnesium (Mg), manganese (Mn), zinc (Zn), and chloride (Cl^-) measured in soil samples.

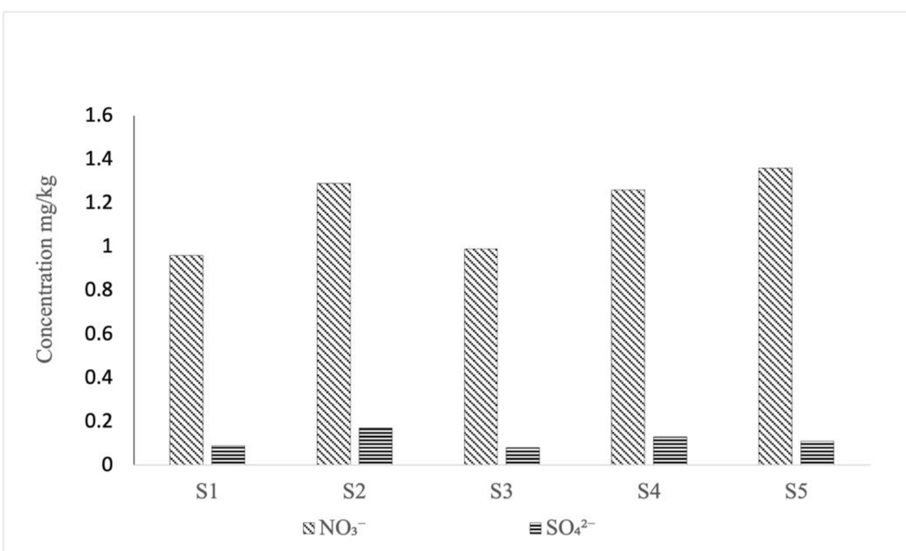

Figure 2b. Concentration of nitrates and sulfates measured in soil samples.

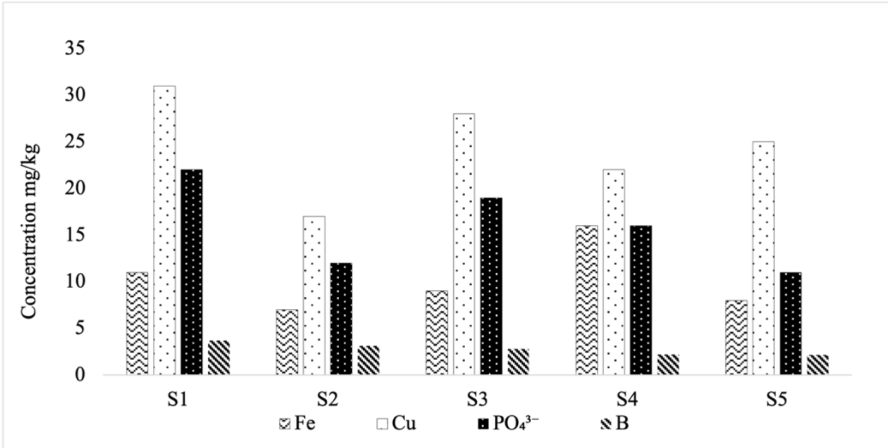

Figure 2c. Concentration of Iron, Copper, Phosphate and Boron measured in soil samples.

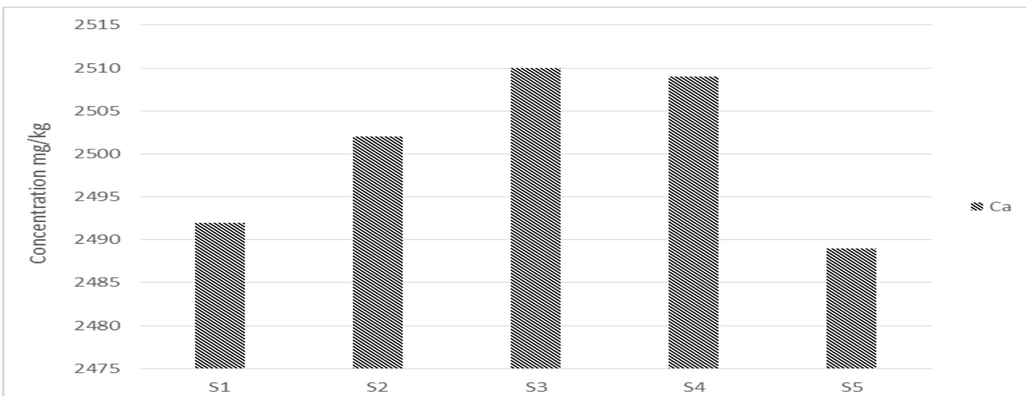

Figure 2d. Concentration of Calcium measured in soil samples.

Water analysis

Concentration of following anions and cations in the hydroponic water samples was analyzed using different methods and analytical techniques. These cations and anions were supplied to the plants using different chemicals mentioned. Concentrations of these elements individually affect the growth and development of plants. Excessive or deficient supply of any of these elements causes several diseases in plants and sometimes causes death to plants and soil microbes. Sample W1, W3, W5, W7 and W9 were taken immediately after mixing of nutrients rich solution in the water for hydroponic plants whereas, W2, W4, W6, W8 and W10 were taken after the interval 1 week after every change. Results showed the percentage of each anion and cations taken up by the plants every week. The average concentrations of Potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Chloride (Cl^-), Boron (B) Nitrate (NO_3^-), Sulfate (SO_4^{-2}) and Phosphate (PO_4^{3-}) observed in water samples taken during the start of every change of hydroponic water were 323mg/L, 203mg/L, 165mg/L, 3.702mg/L, 0.84 mg/L, 3.042 mg/L, 0.43mg/L, 118mg/L, 0.138mg/L, 140mg/L, 163mg/L and 89mg/L respectively. Whereas, average concentration of these cations and anions observed in water samples taken after the 1 week of every change of hydroponic water were 166mg/L, 84mg/L, 62mg/L, 0.78mg/L, 0.46 mg/L, 0.65 mg/L, 0.21 mg/L, 68 mg/L, 0.05 mg/L, 74 mg/L, 66 mg/L and 44 mg/L. In our results 52%, 58%, 62%, 79%, 45%, 79%, 51%, 42%, 64%, 47%, 60% and 51% of Potassium (K), Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Chloride (Cl^-), Boron (B) Nitrate (NO_3^-), Sulfate (SO_4^{-2}) and Phosphate (PO_4^{3-}) respectively had been taken up by the plants during the Experiment of 60 days.

Growth and Germination

After 20 days of seed sowing, the germination percentage of all five plant species was recorded separately. The 19 seeds were successfully germinated for tomato and eggplant resulting in a splendid germination percentage of 95%. While both green chili and okra showed impressive germination percentage of 100% means all the seeds were successfully germinated. However, Lettuce showed a minimum percentage of 85%.

Plant Length

Seedlings used for both Hydroponics and soil based experiments had almost similar length. Length of the Tomato seedlings were between 14 cm to 15 cm. The length of Eggplant seedlings was between 8-9 cm. The length of Lettuce seedlings were 7-10 cm. Green Chili seedlings were 8-9 cm and Okra seedlings were 10 cm to 14 cm.

Soil Plants

The length of tomato plants exhibits a final length ranging from 28 cm to 29 cm. The eggplant reached a length between 15 cm to 18 cm. Lettuce achieved a length of 14 cm to 16cm. Among the Green Chili plants, one titled as G1 showed retarded growth, reaching a length of 15 cm whereas other plants of the same species measured 20 cm and 30 cm, respectively. Okra showed the length range of 25-27 cm.

Hydroponic Plants

In Hydroponics, Tomato plants reached a final length with a range of 31 cm to 32 cm. Eggplant grew to the length of 24-26 cm. Lettuce plant exhibits a uniform length of 16 cm across all studied Vegetables. Notably, one Green Chili plant titled as G1 showed exceptional growth, reaching a length of 45 cm which was highest among all the studied Vegetables whereas, remaining Green Chili plants measured 35cm and 28cm, respectively. Okra showed the length range of 31cm to 32cm in Hydroponics.

Length of Roots

The root measurement of plants was done with the help of measuring scale in cm twice during the experiment. Once, when seedlings were transferred to their respective medium and secondly after the 60 days of seedling transplantation.

Soil Plants

The root length of tomato plants exhibits a final length ranging from 7 cm to 8 cm. While, the roots of Eggplant reached to the length between 6 cm to 8 cm. Lettuce roots achieved a length of 6 cm to 7 cm. Among the Green Chili plants, G1 showed retarded root length of 4 cm whereas, root of other plants of the same species measured 6 cm and 7 cm, respectively. Okra showed the length range of 5 cm to 7 cm.

Hydroponic Plants

In Hydroponics, Tomato roots reached a final length with a range of 8 cm to 9 cm. Eggplant roots grew to the length of 7 cm to 8 cm. Lettuce roots reached a length ranging between 7.5 cm to 10 cm. Green Chili plants' roots reached a length range of 8 cm to 9 cm. Okra showed the root length range of 6.5 cm to 8 cm in Hydroponics.

Total Number of Leaves per Plant Specie

Seedlings utilized in both Hydroponics and soil based experimental setups had almost a similar number of leaves on their stems. The leaves counted manually for all these seedlings were in between a range of 3 to 5.

Soil Plants

The leaves count for tomato plants ranged from 11 to 13. Eggplant had 5 to 7 numbers of leaves. Lettuce achieved 4-6 leaves. Green Chili plants have 11, 14 and 16 leaves on G1, G2 and G3 plants, respectively.

Hydroponic Plants

In Hydroponics, T3 plant of Tomato recorded 22 number of leaves while, T1 and T2 had 12 and 16 leaves, respectively. Eggplants had 7-8 numbers of leaves. Lettuces had 6-7 numbers of leaves. Notably, Green Chili plants titled as G1, G2 and G3 had 19, 22 and 17 numbers of leaves whereas Okra recorded 11-12 numbers of leaves.

Weight of Plants

The seedlings of all the plants used in both soil-based and hydroponics experimental setup showed almost the same weight in grams which was ranging between 3-5 g.

Soil Plants

The weight of tomato plants ranged from 16g to 17g. Eggplant weighed 13 to 14g. Lettuce had weigh between 18-19g. The G1 plant of Green Chili had the lowest weight of 11g whereas, other two had 18 and 22g weight. Okra had a weight of 22, 24 and 26g for O2, O3 and O1 respectively.

Hydroponic Plants

In Hydroponics, the weight of tomato plants ranged from 20g to 22g. Eggplant had 22 to 23g weight. Lettuce had weigh between 18-19g. The Green Chili plants had weights of 39g, 30g and 27g for G1, G2 and G3 respectively. Whereas, Okra had weight of 28, 26 and 31g for O1, O2 and O3 respectively.

Evapotranspiration Rate (E) in Plant

Plant efficiency analyzer LCI T instrument was used to observe the evapotranspiration rate of plants. For soil based plants, the maximum average recorded evapotranspiration rate was 0.27 $mg/m^2/s$ in Lettuce whereas the minimum average recorded value was 0.10 $mg/m^2/s$ for tomatoes.

In hydroponic plants, the maximum average evapotranspiration rate was 0.27 mg/m^2/s for green chili and the minimum recorded average value was 0.11 mg/m^2/s for tomatoes.

Carbon in intercellular spaces (Ci) of Plants

Plant efficiency analyzer LCI T instrument was used to observe the carbon in intercellular spaces (Ci) of plants. For soil based plants, the maximum average recorded Ci rate was 865 μmol/m^2/s in Okra whereas the minimum average recorded value was 387 μmol/m^2/s for tomatoes. In hydroponic plants, the maximum average Ci rate was 770 μmol/m^2/s for green chili and the minimum recorded average value was 298 μmol/m^2/s for tomatoes shown in and Figure 3.

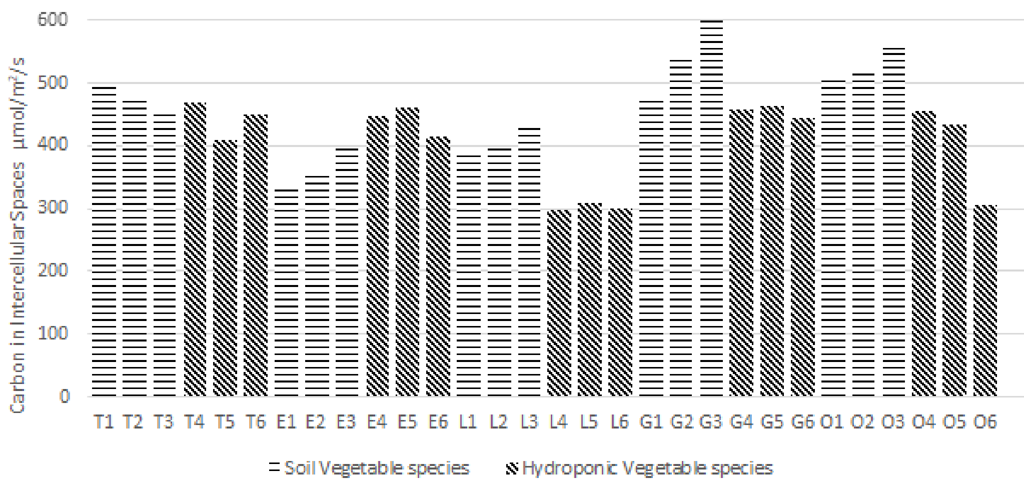

Figure 3. Average Carbon in Intercellular Spaces (Ci) measured for each studied Vegetable species.

Photosynthetic Rate (A) of Plants

Plant efficiency analyzer LCI T instrument was used to observe the photosynthetic rate of plants. For soil based plants, the maximum average recorded photosynthetic rate was 13.6 μmol/m^2/s in Eggplant whereas the minimum average recorded value was 0.46 μmol/m^2/s for Okra. In hydroponic plants, the maximum average photosynthetic rate was 17.4 μmol/m^2/s for Eggplant and the minimum recorded average value was 0.7 μmol/m^2/s for Lettuce as shown in Figure 4.

Stomatal Conductance (gs) in Plants

Plant efficiency analyzer LCI T instrument was used to observe the stomatal conductance rate of plants. For soil based plants, the minimum average recorded stomatal conductance rate was 0.01

μmol/m²/s in Green chili, Tomato and Eggplant whereas the maximum average recorded value was 0.05 μmol/m²/s for Lettuce. In hydroponic plants, the minimum average stomatal conductance rate was 0.00 μmol/m²/s for Green Chili and the maximum recorded average value was 0.06 μmol/m²/s for Okra and Eggplant (figure 5).

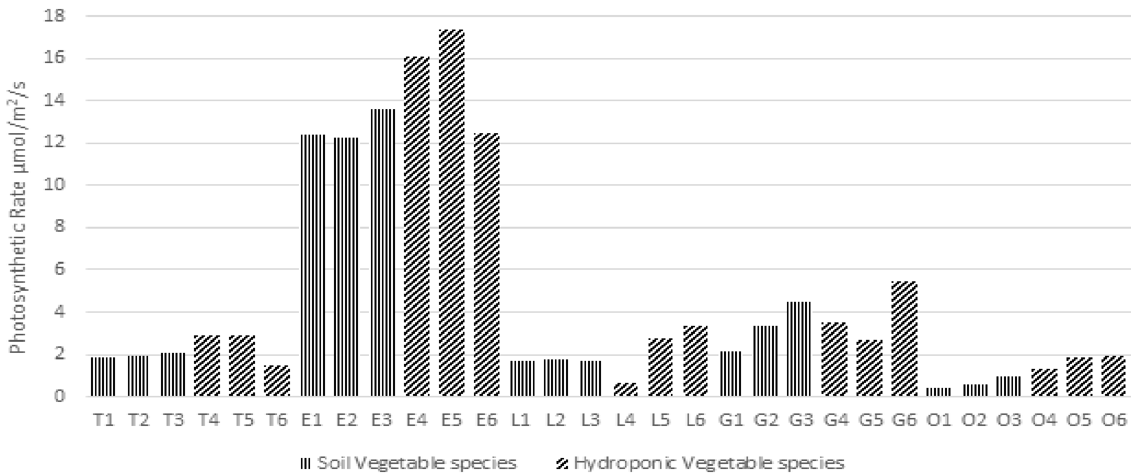

Figure 4. Average Photosynthetic Rate (A) measured for each studied Vegetable species.

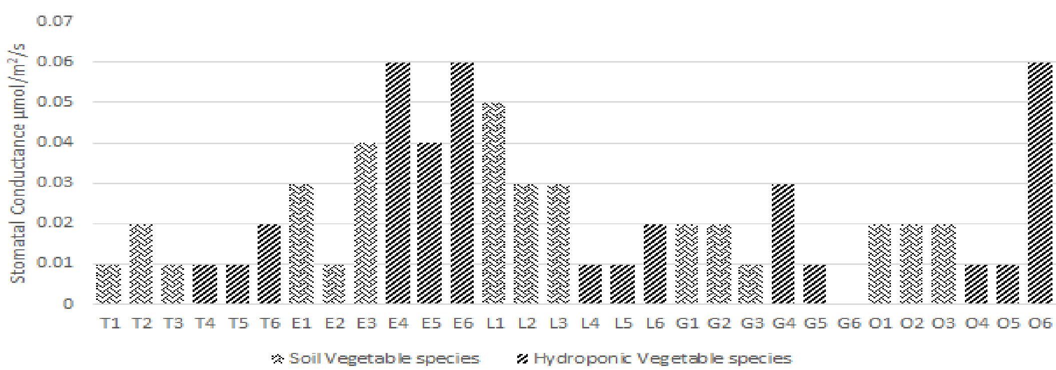

Figure 5. Average Stomatal Conductance Rate (gs) measured for each studied Vegetable species.

The average pH value in the water and soil samples was determined to be 7.6, indicating a medium alkaline condition. This finding is consistent with Rajput et al.'s (2017) study analyzing the physico-chemical characteristics of guava orchards in Larkana, Pakistan. Soil pH is pivotal for promoting plant growth, as extreme acidic or alkaline pH levels can adversely impact microbial growth and soil structure, ultimately leading to inhibited plant growth (Cho et al., 2016). Studies suggest that the optimal soil pH range for plant growth lies between 5.5 and 6.5, mirroring the pH value recorded for the hydroponic system (Singh & Dunn, 2016). However, hydroponic plant species also exhibit growth constraints in low pH conditions below 5.7 (Anukool et al., 2012). Our results for potassium (K) concentration align with Barbagelata's study (2006), which reported K concentrations ranging from 140 to 210 mg/kg in soil samples. Schulte's research (1992) highlights that neutral soils typically exhibit high pH and magnesium (Mg) concentrations exceeding 500 mg/kg. On a global scale, Mn content varies from 270 to 525 ppm (Kabata-Pendias, 2000). However, the zinc (Zn) content in our soil samples exceeded the permissible limit set by the World Health Organization (WHO) at 50 mg/kg (Ogundele et al., 2015). The normal chloride (Cl-) concentration in soils is approximately 100 mg/kg (Geilfus, 2019), falling within the global range of 56 to 305 ppm (Kabata-Pendias, 2000).

Excessive nitrate uptake through various food sources can lead to gastrointestinal cancer (Rao & Puttanna, 2000). Our results indicate an extremely low nitrate concentration, necessitating supplementation through fertilizers. Our copper (Cu) content aligns with the WHO permissible limit of 36 mg/kg (Ogundele et al., 2015). Soil boron content worldwide ranges from 2 to 200 mg/kg (Arunkumar et al., 2018). Comparable to our results, research notes that clayey soils tend to have calcium concentrations exceeding 2500 mg/kg (Espinoza et al., 2012).

Research by Chen et al. (2021) demonstrates that varying phosphorus concentrations (1 mM – 5 mM) supplied as KH2PO4 do not impact leaf number or plant height. Our lettuce results agree with de Souza et al.'s (2019) study, which showed hydroponic lettuce reaching 33 cm in length, twice that of our hydroponic lettuce, while soil-based lettuce achieved 15 cm, like ours. Olutola et al.'s (2020) comparative study on okra growth in hydroponics and conventional farming aligned with our hydroponic okra height of 38 cm and their conventional farming height of 31 cm. Ahmadi & Souri's (2020) four-month chili pepper study yielded an 88 cm height under controlled conditions. Given our G4 hydroponic plant's growth, extending the experiment to 4 months could have achieved similar heights. Overall, hydroponic system-grown plants exhibited longer roots than their soil-based counterparts. Siddiq (2012) found that Tomato root length was maximized with higher applied CaC_2 (15 mg). Grunhofer et al.'s (2021) hydroponic P. × canescens roots reached 13 cm under controlled conditions, surpassing our experiment's roots. Optimal root, shoot, and leaf growth rates occur at a flow rate of 4 L/min (Baiyin et al., 2021). Excessive iron (Fe) levels (up to 400 ppm) hinder root growth (Turhadi et al., 2018). For lettuce, de Souza et al. (2019) reported 50 cm hydroponic and 30 cm soil lettuce roots, significantly more than our results.

In terms of leaf numbers, our hydroponic-grown plants exceeded their soil-based counterparts. Lettuce leaves have economic importance in salads and fast foods (Lipton & Ryder, 2021). Okra leaves contain silica, protecting against harmful UV rays (Pierantoni et al., 2017). Changes in auxin levels lead to diverse tomato leaf forms (Shwartz et al., 2016). A four-month chili pepper study (Ahmadi & Souri, 2020) recorded 94 leaves. Extending our experiment to 4 months could yield comparable numbers for G2 (soil) and G4 (hydroponic). Olutola et al. (2020) in a 7-month okra study reported 116 hydroponic and 81 conventional farming leaves, potentially achievable in our experiment with an extended timeframe.

CONCLUSIONS AND RECOMMENDATIONS

The temperature observed during the course of the experiment was between 30-37^{o}C that was best for the growth of selected vegetables. All selected seeds showed an impressive germination rate. Different morpho physiological parameters of selected plant species were studied in both soil and hydroponic experiments. However, Green chili showed the highest growth in terms of height, weight and number of leaves. However, Lettuce showed the lowest growth rate in both experiments. The overall result showed that the hydroponic system had provided positive results for the Selected Vegetable as compared to soil based plants. The experiment revealed no plant mortality, suggesting optimal growth conditions. However, soil analysis was carried out to identify the concentration of different anions and cations. The concentrations of all the elements in the soil were normal (neither toxic nor deficient) and no additional fertilizers were added into the soil. Results of water analysis showed percentages of different anions and cations taken up by all the plants during the experiment. No EC was calculated for soil and water samples. This research results showed that hydroponic system has ability to achieve related sustainable development goals such as climate action, responsible consumption and production, industry, innovation and infrastructure, good-health and wellbeing, and zero hunger. However, the duration of experiment is recommended to increase and wait for the fruit development. The fruit nutrition testing comparison of hydroponic and soil grown plants should be carried out to understand and ensure which system is majorly promoting human and environmental health safety. Study should be extended to make nutrient rich hydroponic solution using a smaller number of chemicals. It is recommended that formulation of hydroponic solution incorporates Epsom salt and NPK fertilizer or natural compost. Hydroponic technique should be used in an open environment under uncontrolled conditions. In addition to current plant selection, experiments should be conducted on climbing vegetables and fruits too. To promote resource efficiency, usage of artificial electricity sources for providing continuous flow of hydroponic water to the roots of plants should be replaced with renewable solar energy.

CONFLICT OF INTEREST

The authors declare no conflict of interest relevant to this research.

AUTHORS DECLARATIONS

The authors declare that the research work presented is original and contributes genuinely to the academic field. All sourced used in research have been properly cited and acknowledged.

AUTHORS' CONTRIBUTIONS

Syeda Zoia Ali Zaidi:
Shaheen Begum:
Mehwish Jamil Noor:
Gul-e-Saba Chaudhry:
Shahbaz Khan:
Muhammad Adnan:

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