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Hydroponics vs Soil: An in-Depth Assessment of Morpho-physiological Traits in Spinach (*Spinacia oleracea*)

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ABSTRACT

Background: Making the switch from traditional soil farming to hydroponics is essential in modern agriculture to maximize resource utilization, guarantee food security and address environmental challenges. In addition to encouraging water conservation and offering exact control over nutrient distribution, hydroponics also holds the potential to increase agricultural production. In contrast, soil-based agriculture is a tried-and-true farming technique that depends on naturally occurring minerals.

Methods: An experiment was conducted to investigate the morpho-physiological response of spinach in hydroponics and in soil during the winter season of 2022. In NFT hydroponics plants were planted using potting mix as a growing media. Hydroponically grown spinach was compared with the traditional grown spinach.

Result: Spinach grown hydroponically exhibited superior leaf characteristics, including a larger leaf area, longer and broader leaves and a higher leaf count per plant. Additionally, hydroponic plants demonstrated enhanced growth traits, such as greater height, longer roots and thicker petioles. Notably, hydroponically grown spinach contained significantly more chlorophyll, indicating improved photosynthetic activity. Furthermore, both hydroponically and soil-grown spinach showed similar levels of nitrogen accumulation, suggesting that hydroponics can effectively support nutrient uptake comparable to conventional methods.

Key words: Growth parameters, Hydroponics, NFT, Spinach.

INTRODUCTION

The agricultural sector strives for efficiency, aiming to produce high-quality yields at the lowest possible cost. The need for food is rising as the world's population is expected to reach 10 billion people by 2050, with 66% living in cities (Ghorbel *et al.,* 2021; Gaikwad and Maitra 2020). According to (Nabi *et al.,* 2022), soil is the most crucial medium for plant growth since it offers anchoring, nutrients and water for crop growth. Land resources are becoming scarcer due to urbanization (Ranawade *et al.,* 2017; Sardare and Admane, 2013). Conventional farming techniques, however, face a lot of difficulties due to various environmental and biodiversity stresses that inhibit and affect the growth and development of plants (Ravindranath *et al.,* 2024; Lalichetti *et al.,* 2023; Gaikwad *et al.,* 2022; Manepalli *et al.,* 2022; Tomar *et al.,* 2021; Gaikwad *et al.,*2020a; Nihal *et al.,* 2019). Under these circumstances, concurrent research has been carried out on various input management practices for agricultural sustainability (Sairam *et al.,* 2024; Kathula *et al.,* 2023; Sagar *et al.,* 2023a,b). Further, soilless agriculture techniques, such as hydroponics, enable cultivation in uncultivable areas with assured quality under controlled environmental conditions (Gaikwad *et al.,* 2020b).

In the soil-free cultivation technique known as hydroponics, plants are grown with their roots exposed to a mineral fertilizer solution. Compared to conventional soil-based culture, this approach enables more effective nutrient uptake (Gaikwad *et al.,* 2022). Hydroponics does away with the need for a soil medium by providing the roots with support from substances like perlite, gravel, or coco peat (Sahoo *et al.,* 2023; Santosh and Gaikwad, 2022). Additionally, it provides benefits including space optimization, disease control and water conservation. Due to its simplicity of use and minimal skill requirements, hydroponics has become more popular in a variety of contexts, including home gardens, offices, airports and industrial landscapes (Pal, 2020; Sankhalkar *et al.,* 2019; dos Santos *et al.,* 2013; Shalini *et al.,* 2018).

Malnutrition and noncommunicable illnesses can be prevented by eating a healthy, balanced diet that includes fruits and vegetables (Czarnowska-Kujawska *et al.,* 2022;

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Kessler *et al.,* 2022). According to (Ko *et al.,* 2014; Vargas *et al.,* 2022), the commonly grown vegetable crop spinach (*Spinacia oleracea* L.), contains important vitamins, minerals and omega-3 fatty acids. Spinach is a viable remedy for this issue because there is a need to enhance daily consumption of vegetables rich in health-promoting elements.

China is the world's top producer of spinach and it is widely grown throughout Asia and Europe. In addition to its economic importance, spinach is a green vegetable crop that is growing in popularity due to its wealth of nutrients that support health, including carotenoids, flavonoids, antioxidants and other phytochemicals (Arru *et al.,* 2021; Koh *et al.,* 2012; Roberts and Moreau 2016). It is crucial to compare the performance of spinach farmed in hydroponics and soil systems due to the significance of spinach and the growing interest in controlled environment agriculture to reduce food shortages and environmental implications (Al-Karaki and Al-Hashimi, 2012).

In this study, we aim to conduct a comparative analysis of the morphological, physiological performance and nitrogen accumulation in spinach cultivated using hydroponics and soil systems. By examining these aspects, we can gain insights into the potential benefits and drawbacks of each cultivation method. This research will contribute to a better understanding of spinach physiology and guide future advancements in agricultural practices.

MATERIALS AND METHODS

The experiment was conducted in the hydroponics unit at Centurion University of Technology and Management, Paralakhemundi, Odisha, India during the winter season of 2022. The experiments were arranged with two growing conditions *viz* hydroponic system (NFT- Nutrient Film Technique) and open field condition (soil grown). Spinach seedlings were raised in pro-trays using potting mix which was prepared with a combination of cocopeat, perlite and vermiculite in 3:1:1 ratio as growing media. These seedlings were ready to transplant in 3 weeks and the seedlings were transferred to a 3-inch mesh pot into the NFT system.

The vertical NFT unit was pyramid-shaped with four tiers having dimensions (L×W×H) of (120×60×150) cm with a reservoir of 20 lit capacity. One vertical NFT system has a capacity of 64 mesh pots. (Fig 1) In each mesh pot, two seedlings were transplanted along with potting mix. Clay balls were placed around the transplanted seedlings to give them support. The nutrient solution (Table 1) was circulated into the NFT channels through a submerged pump (40-watt) and excess water was collected back to the reservoir. During recirculation, the flow rate was maintained up to 1.5L per minute. The nutrient solution was replaced every 15 days intervals. pH of 5.5-6.5 and EC of 1.0-1.2 dSm^{-1} was maintained in hydroponic nutrient solution during the early growth stage. It was further increased up to 2.6-2.8 dS m^{-1} during the maturity stage. Spinach was also traditionally grown in open field soil with a spacing of (15×15) cm for comparative study with hydroponics. Soil texture and initial nutrient status of the soil is mentioned in Table 2. Fertilizers were applied at the rate of 80:60:60 kg/ha. (Gowda *et al.,* 2022)

All experimental data were expressed as mean ± standard deviation using statistical analysis with SPSS 16 (SPSS Corporation, Chicago, Illinois, USA) and MS Excel 2007. Differences between mean values were evaluated using an independent t-test. The differences were compared with a significance level of 0.05.

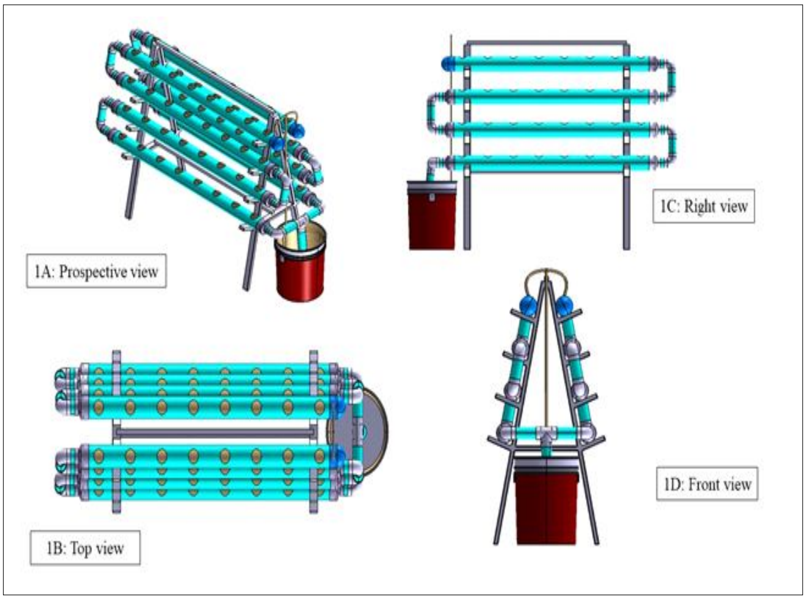

Fig 1: 3D illustration of 64 planter NFT hydroponics structure.

Table 1: The composition of the modified Hoagland nutrient solution.

Compounds		Concentration of stock solution (mM)	Volume of stock solution per liter of final solution (ml)
Macronutrients	KNO_3	1000	6
	$Ca(NO_3)_2.4H_2O$	1000	4
	KH_2PO_4	1000	2
	$MgSO_4.7H_2O$	1000	1
Micronutrients	KCL	25	2
	H_3BO_3	12.5	
	$MnSO_4.H_2O$	1.0	
	$ZnSO_4.7H_2O$	1.0	
	$CuSO_4.5H_2O$	0.25	
	MoO_3	0.25	
	Fe Na EDTA	64	1

Table 2: Soil texture and initial nutrient status of soil.

Particulars	Values
Texture	Sandy loam
Soil pH	6.32
EC mS cm^{-1}	0.18
Organic carbon (%)	0.34
Available N (kg ha^{-1})	125
Available P (kg ha^{-1})	21
Available K (kg ha^{-1})	142

At the full growth stage data were recorded on leaf area, leaf length, leaf width, leaves per plant, fresh leaf weight per plant, dry leaf weight per plant, fresh weight per plant, yield, plant height, root length, petiole length, fresh root weight per plant, dry root weight per plant, fresh petiole weight per plant, dry petiole weight per plant, total chlorophyll content, leaf nitrogen content, petiole nitrogen content and root nitrogen content. Total chlorophyll content was estimated by employing the procedure described by Arnon (1949) and the nitrogen content of leaf, petiole and root was estimated by the Kjeldahl method.

RESULTS AND DISCUSSION

The effect of hydroponics compared to soil-grown conditions on leaf parameters and yield is presented in Table 3. A significant difference was observed in leaf area, leaf length, leaf width, number of leaves per plant, fresh leaf weight per plant, dry leaf weight per plant and yield while the difference was non-significant in the case of fresh weight of plant. In hydroponics conditions, the leaf area was found to be 221.6 cm^2 and in soil-grown condition it is 181.4 cm^2. It is pertinent to say that spinach grown in hydroponics system has developed a profuse leaf system as compared to soil-grown condition. Leaf length and width in the hydroponics system were found to be 15.21 cm and 8.24 cm respectively whereas in soil grown system it is 12.23 cm and 7.36 cm respectively. The fresh weight of the plant in hydroponics condition is 77.07 g whereas in the field it is 47.28 g. Though the fresh weight of the plant in hydroponics and soil-grown conditions is at par, in the hydroponics system it is as high as 94.5 g and in soil-grown conditions, it is 55.97 g. Plant nutrients are readily available in hydroponics system through nutrient solutions for easy plant uptake as a result leaf parameter shown better performance in hydroponically grown conditions as compared to soil (Abu-Shahba *et al.,* 2021). Also, plant with strong root system generates a greater amount of foliage increasing the absorption of solar radiation for synthesizing photo-assimilates (Lin *et al.,* 2013).

Spinach in the hydroponics system had shown significantly higher yield as compared to soil grown condition *i.e.*, 3.43 kg m^{-2} and 1.2 kg m^{-2} in hydroponics and soil grown condition respectively. In hydroponic conditions, spatial expansion leads to an increased yield per land area. A similar type of result was found by Acharya *et al.,* 2021.

The effect of hydroponics compared to soil grown conditions on morphological parameters such as plant height, root length, petiole length, fresh root weight, dry root weight, fresh petiole weightand dry petiole weight per plant of spinach are presented in Table 4. A significant difference was observed in all the parameters. In hydroponics, plant height was found to be 51.6cm whereas in soil it is 24.8 cm. A root length of 28 cm was observed in hydroponically grown spinach while in soil grown it was found to be 11.2 cm. Similarly, petiole length was 12.16 cm and 6.2 cm in hydroponics and soil-grown conditions respectively. While looking into fresh root weight and dry root weight it was found significantly more in hydroponics than the soil grown condition. A similar type of result was found for fresh petiole weight per plant and dry petiole weight per plant. The beneficial effect of a hydroponics system that is under protected conditions may result in the above-mentioned observation.(Agarwal *et al.,* 2019; Gashgari *et al.,* 2018) has also reported a similar type of results.

Chlorophyll content and nitrogen accumulation

The effect of hydroponics compared to soil-grown conditions on chlorophyll content and nitrogen accumulation is

Table 3: Leaf and yield parameters of spinach in a hydroponic system and soil grown condition.

Growing conditions	Leaf area (cm^2)	Leaf length (cm)	Leaf width (cm)	Leaves $plant^{-1}$	Fresh leaf weight $plant^{-1}$ (g)	Dry leaf weight $plant^{-1}$ (g)	Fresh weight $plant^{-1}$ (g)	Yield (kg m^{-2})
Hydroponics	221.6±5.59	15.21±0.20	8.24±0.17	14.2±0.30	77.07±1.56	6.54±0.15	94.5±1.11	3.43±0.03
Soil	181.4±3.80	12.23±0.06	7.36±0.10	13.1±0.18	47.28±2.12	4.75±0.03	55.97±0.30	1.2±0.03
P Value (0.05)	0.01	0.00	0.01	0.00	0.00	0.00	0.05	0.00

Table 4: Response of hydroponic system and soil condition on plant height, root and petiole length and fresh and dry weight of spinach.

Growing conditions	Plant height (cm)	Root length (cm)	Petiole length (cm)	Fresh root weight $plant^{-1}$ (g)	Dry root weight $plant^{-1}$ (g)	Fresh petiole weight $plant^{-1}$ (g)	Dry petiole weight $plant^{-1}$ (g)
Hydroponics	51.6±1.04	28±0.38	12.16±0.05	11.09±0.10	1.38±0.02	6.34±0.07	0.435±0.01
Soil	24.8±0.50	11.2±0.48	6.2±0.03	4.52±0.05	0.91±0.01	4.17±0.04	0.328±0.01
P Value (0.05)	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5: Chlorophyll content and nitrogen accumulation of spinach in hydroponic system and soil grown condition.

Growing conditions	Chlorophyll content (mg g^{-1})	Leaf nitrogen content (mg g^{-1})	Petiole nitrogen content (mg g^{-1})	Root nitrogen content (mg g^{-1})
Hydroponics	0.67±0.01	0.56±0.02	0.48±0.01	0.62±0.01
Soil	0.58±0.01	0.53±0.03	0.47±0.01	0.6±0.03
P Value (0.05)	0.00	0.223	0.778	0.335

presented in Table 5. The total chlorophyll content of spinach grown in hydroponics was found to be 0.67 mg g^{-1} which is significantly higher than the spinach grown in soil conditions. In soil-grown conditions, the total chlorophyll content was found to be 0.58 mg g^{-1}. A similar type of result was reported by (Agarwal *et al.,* 2021) suggesting growing conditions resulting in differences in chlorophyll content. Investigating nitrogen accumulation in the root, petiole and leaf under soil-grown and hydroponic growing circumstances produced statistically at-par results, however, the amount of nitrogen deposited in the root is higher than in the leaf and petiole. This is an area that needs to be explored.

CONCLUSION

A study compared hydroponic and conventional soil systems for growing spinach and revealed that Hydroponics provided superior leaf characteristics, including greater leaf area and higher leaf count. This response may be due to the hydroponic system's effective nutrient supply and improved growing conditions. Hydroponically grown spinach also displayed impressive growth in plant height, root length, and petiole length. The hydroponic system's regulated atmosphere encouraged strong root growth and overall plant growth. Hydroponically grown spinach had higher fresh and dry weights, highlighting its potential for greater output. Hydroponic spinach also had higher levels of chlorophyll, indicating enhanced photosynthesis and plant vigor. Nitrogen accumulation was similar in both hydroponic and soil-grown spinach. The study highlights hydroponics as a viable and efficient method for spinach cultivation. Further research can optimize hydroponic spinach cultivation for sustainable food production.

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Authors' contribution

Dinkar J Gaikwad provides the main concept of the work. Chandrasekhar Sahu and Ashirbachan Mahapatra did the literature study. S. Prasanth and B. Divya collected the data and performed lab analysis. Kousik Atta and D.S Jaswanth helped with manuscript writing. All authors provided critical feedback and shaped the research, analysisand manuscript.

Declaration

Ethical approval

Authors declare this manuscript does not include any studies using animal and human beings.

Consent to publication

All authors read and approved the final manuscript.

Conflict of interest

The authors declare no conflict of interest.

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