



Evaluating the Growth Parameters of Chili in Hydroponics using the Nutrient Film Technique (NFT): A Sustainable and Efficient Alternative to Traditional Agriculture

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ABSTRACT

Background: Hydroponics has recently gained much importance in the field of sustainable way of practicing agriculture. Large-scale cultivation of commercially important crops has seen the bad effects of environmental stress of drought, saline conditions which decrease the annual crop production and moreover usage of harmful pesticides has become a major health concern. Growing and producing vegetables using controlled conditions in hydroponics showed a promising way of cultivating crops irrespective of season and geographical area.

Methods: Techniques like Nutrient film technique (NFT) help in providing nutrients and minerals directly to the roots in a precise manner and involving in recirculation of water which eventually avoid the salts accumulation. Present study focusses on cultivation of high demand crop, chili (*Capsicum annuum*), well known for its value-addition, medicinal properties and possess high economic significance with high export potential using NFT technique.

Result: The results shown that, the parameters influencing the plant's growth and yield such as electrical conductivity (EC), potential of hydrogen (pH), total dissolved solids (TDS) and temperature of the nutrient solution with highest frequency are in the range of 1660-1860 $\mu\text{S/cm}$, 4.7-5.0, 899-989 ppm and 28.4-29.4°C. The statistical methods, Pearson Correlation matrix showed the relation between the number of fruits produced and nutrient solution parameters where, EC, TDS and temperature showed a positive correlation while pH formed a negative correlation. The current study provides valuable insights for cultivating chili through NFT hydroponics.

Key words: Chili, Growth conditions, Hydroponics, NFT.

INTRODUCTION

Population growth and the necessity for sustainable food supply have required the investigation of novel agricultural practises. Hydroponics, the growing of plants without soil, has developed as a viable alternative to conventional agriculture. The Nutrient Film Technique (NFT) is a very effective hydroponic method for increasing crop yields and resource efficiency (Jones, 2016). In this study, we examine the growing of chilli (*Capsicum annuum*) utilising the NFT hydroponic system, showing its advantages compared to conventional soil-based techniques.

Hydroponic systems provide various benefits over conventional agriculture, including lower water and fertiliser usage, reduced risk of soil-borne illnesses and enhanced plant growth control (Raviv and Lieth, 2007). Specifically, the NFT approach enables the continuous flow of nutrient-rich water over plant roots, maximising nutrient and oxygen availability (Resh, 2012). This may lead to quicker growth rates, increased yields and enhanced crop quality (Jensen, 1999).

Contemporary observations revealed the presence of pesticide residues on chili fruits even (Sulaiman and Zakaria, 2022), which are commonly used against pests and mites in the traditional cultivation of *C. annuum* (Nasrin *et al.*, 2021). Growing chilli plants in a hydroponic NFT system may offer a more efficient and sustainable means of satisfying the expanding demand for this popular crop,

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which is valued for its flavour and possible health advantages (Saleh, 2018). Recent research has shown that hydroponic systems may greatly boost chilli yields compared to conventional soil-based production (Hernández *et al.*, 2021). The purpose of this paper is to examine further the ideal conditions and procedures for chilli production utilising the NFT hydroponic system and to provide insights for both small-scale and commercial farmers.

MATERIALS AND METHODS

Location

The experiment was performed in the Department of Biotechnology, Vikrama Simhapuri University, Nellore, Andhra Pradesh, for a total period of fifteen weeks (120 days) from September 2024 to December 2024. Experimental plots were kept in shade-net house, covered with green shade net (50% shade) of 10 ft × 5 ft × 12 ft (length × wide × height).

Plant material

Seeds of *Capsicum annuum* were sown in the inert foam material placed in the water bath (distilled water) for two weeks for seeds to germinate and covered with thin sheets and placed in dark as light will cause unwanted algae to grow in water. It was checked regularly for growth of seedlings from seeds for two weeks.

Treatments and substrates

We evaluated it through nutrient film technique (NFT) hydroponics system. The substrates used were clay balls and inert foam material (Purchased via Amazon.co.in). Macronutrients and micronutrients purchased from GreenLoop (LEAFY 200). They were prepared as stock solutions (A and B). Stock A was prepared by adding 160 gm of nutrient mix to 1 litre of R.O water and Stock B was prepared by adding 170 gm of nutrient mix to 1 litre of R.O water separately. The macronutrients composition includes Ca 23%, N 23%, P 7%, K 32%, Mg 5.3%, S 9% and micronutrients composition of 0.7% each B, Cl, Mn, Zn, Cu, Na, Mo, Fe, C. For the first time, the NS supplied was half-strength where 10ml of each stock A and stock B were added to 40 L of distilled water (TDS-50 ppm).

NFT hydroponic system

The NFT system was composed of an underground 20-L tank (PVC), an 45(W) Sub-immersible pump (18.8 × 15.5 × 12.2 cm; 778 Grams, amici Tools- India), 12.5-mm water supply pipe (RO), two 7 ft -110 mm 4 kgf/cm² medium cylindrical hydroponic channels (Kumar pipes, Pvt Ltd., Nellore, Andhra Pradesh) and 38-mm drain pipe and with a 6% slope of PVC pipes to allow NS return to the tank. The seedlings were spaced every 20 cm.

Two weeks old seedlings (n=15) of *C. annuum* were transferred into the NFT system. From the day after transplant (DAT) until the end of the experiment, the pump was turned on continuously from morning till night because plants require a continuous supply of nutrients (Graves, 1983; Graves and Hurd, 1983). The pump was turned off for one hour in the morning and in the evening or intervals of up to 5 min to promote adequate plant watering and nutrition (Zanella *et al.*, 2008).

Water- pH, EC and TDS

The water used was distilled water and had the following characteristics: pH-5.9, electrical conductivity (EC)- 100 µS/cm and TDS -50 ppm. The pH was kept between 4.5 to

5.6 using hydrochloric acid (HCL) or sodium hydroxide (NaOH) 1 N solution to maintain the chelates in a stable form (Ferrarezi *et al.*, 2007), with daily replenishment (Furlani *et al.*, 1999) and weekly replacement to avoid nutrient concentration fluctuations.

Parameters evaluated

Daily checks were made on the EC, pH and TDS in the substrates and the NS from NFT tanks. An adaptation of addition of R.O water at an interval of every two weeks *i.e.*, at the end of 2nd, 4th, 6th, 8th, 10th, 12th and 14th weeks and addition of stocks (A and B) with half-strength at the end of 2nd, 4th weeks and full-strength is provided at the end of 6th, 8th and 12th weeks was done to maintain stable EC, pH and TDS levels in NS. The temperature in the nutrient solution (NS) tank was checked periodically and maintained at 25-30°C, as the absorption rate of nutrients will decrease with rise in the temperature.

Biometric parameters

Root length, shoot height, number of leaves, number of nodes, was recorded D.A.T. (Date After Transplant) 7, 14, 28, 35 and 42. In addition to parameters like electrical conductivity (EC), pH, total dissolved solids (TDS) and temperature were measured and recorded daily from the 1st week (DAT 1) until the 6th week (DAT 42) to analyse and compare the plant's growth performance in relation to the nutrient solution (NS) present in the tank for six weeks. Chilli fruit setting was observed after 6 weeks from transplanting. After fruit setting, the parameters like, EC, TDS, pH and temperature of the nutrient solution was checked once at the end of the week, from 7th week till 12th week.

Statistical analysis

All the biometric parameters are calculated using mean± standard deviation with significance (p<0.05). The Pearson Correlation Analysis (PCA) is employed between the number of chili fruits, EC, TDS, pH and temperature to find out the parameter influencing most along with the relationship among them. It is done via Python language using the libraries such as Pandas for data frame management, SciPy for statistics (PCA) and Seaborn for visualization (Virtanen *et al.*, 2020; Ranjan *et al.*, 2023; Rogel-Salazar, 2023; Virtanen, 2023).

RESULTS AND DISCUSSION

The biometric growth parameters of *Capsicum annuum* along with environmental parameters were monitored over a period of six weeks, from day 1 to day 42. The biometric parameters measured were shoot length, root length, number of leaves, number of nodes and shoot-to-root ratio. The mean and standard deviation of each parameter were calculated at each time point.

The shoot length of the *C. annuum* plant increased significantly over time, from a mean of 0.94±0.20 cm on day 7 to 34.93 cm±0.34 cm at day 42. The root length also

increased steadily, from a mean of 0.75 cm $\pm$ 0.12 cm on day 7 to 19.74 cm $\pm$ 0.26 cm at day 42. The number of leaves and nodes showed a similar trend, increasing rapidly between days 14 and 28 and then levelling off at later time points. The number of leaves increased from a mean of 2.53 $\pm$ 0.51 in the first week (day 7) to 47.46 $\pm$ 1.45 in the sixth week (day 42). The number of nodes increased from a mean of 1.46 $\pm$ 0.51 in the first week (day 7) to 15.33 $\pm$ 0.72 in the sixth week (day 42). The shoot-to-root ratio also varied over time, with a mean ratio of 1.25 at day 7 increasing to 1.94 at day 21 and then gradually decreasing to 1.76 at day 42 (Table 1). The environmental factors also showed significant variation during the six weeks. The EC ranged from 1480 to 2670 μ S/cm, pH ranged from 4.6 to 5.65, TDS ranged from 719 to 1330 ppm and temperature ranged from 23.4°C to 31.1°C (Table 2).

Fruit setting

After six weeks of growth in NFT hydroponics, green fruits with a length of 3-4 cm were observed. At the end of 7th week mature fruits with an average length of 6 cm were

developed which are ready for harvesting. At the end of 13th week, the NFT grown chilli plants had an average yield of 70 chillies with a mean standard deviation of 70.4 $\pm$ 1.8 (Table 3). The number of fruits per plant ranged from 40 to 70, with an average weight of 10-12 grams per fruit. The fruit setting rate was found to be high, with an average of 90% of flowers successfully developing into fruits (Fig 1).

Pearson correlation analysis (PCA)

PCA results between number of chili fruits and other nutrient solution parameters are presented in (Table 4). The Pearson coefficient for number of fruits with EC, pH, TDS and temperature are, 0.64, -0.86, 0.65 and 0.67 respectively.

The study investigated the growth and development of chili plants in a nutrient film technique (NFT) hydroponic system. The results of this study indicate that the chili plant undergoes significant growth and development over a six-week period without any usage of pesticides and other harmful chemicals. The lengths of shoot, root and number of leaves and nodes all increased over time, with the most

Table 1: Growth parameters of *Capsicum annum* in hydroponically cultivated using NFT for 6 weeks.

Biometric parameters	DAT 7 (1 st week)	DAT 14 (2 nd week)	DAT 21 (3 rd week)	DAT 28 (4 th week)	DAT 35 (5 th week)	DAT 42 (6 th week)
Shoot length (cm) (Mean $\pm$ S.D)	0.94 $\pm$ 0.20	3.98 $\pm$ 0.20	8.99 $\pm$ 0.26	13.96 $\pm$ 0.13	22.03 $\pm$ 0.46	34.93 $\pm$ 0.34
Root length (cm) (Mean $\pm$ S.D)	0.75 $\pm$ 0.12	2.67 $\pm$ 0.22	4.63 $\pm$ 0.24	7.59 $\pm$ 0.33	11.85 $\pm$ 0.23	19.74 $\pm$ 0.26
No. of leaves (Mean $\pm$ S.D)	2.53 $\pm$ 0.51	6.4 $\pm$ 1.05	12.33 $\pm$ 1.04	24.06 $\pm$ 1.33	34.73 $\pm$ 1.62	47.46 $\pm$ 1.45
No. of nodes (Mean $\pm$ S.D)	1.46 $\pm$ 0.51	2.33 $\pm$ 0.48	4.26 $\pm$ 0.45	8.33 $\pm$ 0.48	11.8 $\pm$ 0.41	15.33 $\pm$ 0.72
Shoot-to-root ratio	1.25	1.49	1.94	1.83	1.85	1.76

Note: Number of replicates maintained (n=15).

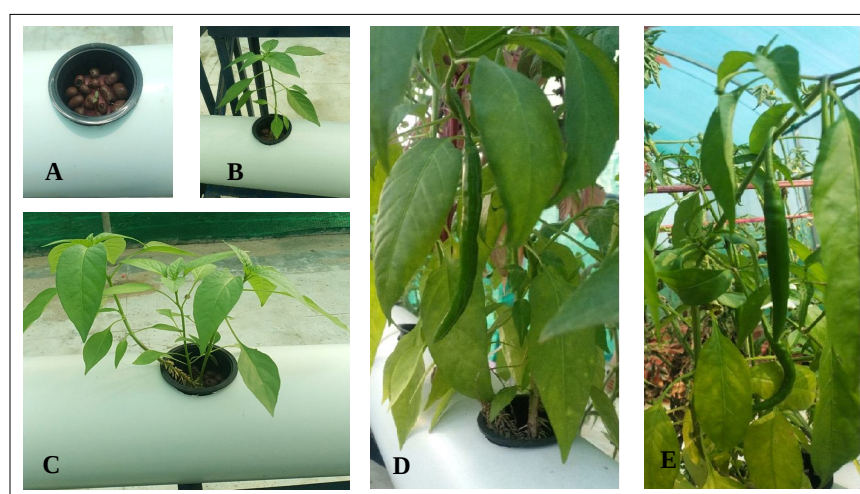


Fig 1: A- Seedling of *Capsicum annum* was transplanted into hydroponic system (NFT)-DAT 1; B, C- Hydroponically grown Chili plant during 3rd week (DAT 21); D, E- Fruit setting in the 8th week.

rapid growth occurring between days 14 and 28. These results are consistent with previous studies on chili plant growth, which have reported similar trends in biometric parameters (Hernández *et al.*, 2021).

The shoot-to-root ratio is an important parameter in plant growth and development, as it reflects the balance between above and below biomass allocation. The results of this study show that the shoot-to-root ratio increased between days 7 and 21. Simultaneously, during this period

EC and TDS levels in the nutrient solution also increased evincing that more nutrients are utilised by the chili plant for shoot growth during this period in NFT. However, the ratio decreased at later, suggesting that more resources are assigned for root development as the plant matures. According to the analysis, the ideal frequency range of EC, pH, TDS and temperature of the nutrient solution is between 1660-1860 $\mu\text{S/cm}$, 4.7-5.0, 899-989 ppm and 28.4-29.4°C respectively.

Table 2: Different parameters observed for *Capsicum annum* in the nutrients supplemented water present in the tank.

Date	EC	pH	TDS (ppm)	Temp(°C)
DAT 1	1480	5.1	740	29.1
DAT 2	2040	5.3	1000	29.5
DAT 3	2020	5.3	1000	29.3
DAT 4	1980	5.3	980	23.4
DAT 5	1900	5.3	930	29.2
DAT 6	1730	5.5	860	29.1
DAT 7	1710	5.5	890	30.2
DAT 8	1690	5.5	880	29.1
DAT 9	1670	5.5	870	30.1
DAT 10	1670	5.4	867	29.1
DAT 11	1640	5.3	818	30
DAT 12	1980	5.1	970	31.1
DAT 13	2670	5	1330	28.4
DAT 14	2030	5.02	1070	31
DAT 15	2050	5.1	1000	31
DAT 16	2080	5	1000	28
DAT 17	1910	4.75	975	29.5
DAT 18	1842	4.6	960	31
DAT 19	1837	4.6	960	31
DAT 20	1825	4.58	971	31
DAT 21	1815	4.8	940	29.2
DAT 22	1813	4.8	937	30
DAT 23	1802	4.8	936	30.5
DAT 24	1790	4.81	922	30.9
DAT 25	1785	4.84	907	29.2
DAT 26	1770	4.85	902	29.6
DAT 27	1750	4.86	900	28.9
DAT 28	1700	4.86	890	29
DAT 29	1685	4.87	869	28
DAT 30	1655	4.89	832	26.5
DAT 31	1623	4.89	830	24.3
DAT 32	1610	4.9	819	25
DAT 33	1585	5	814	29.1
DAT 34	1565	5.05	782	29.9
DAT 35	1562	5.1	780	30.1
DAT 36	1558	5.17	781	29.4
DAT 37	1558	5.25	780	28.7
DAT 38	1555	5.33	778	27.5
DAT 39	1555	5.47	778	28
DAT 40	1550	5.51	776	27.6
DAT 41	1477	5.65	732	27.3
DAT 42	1460	5.65	719	26

Table 3: Impact of nutrient solution (Parameters -EC, pH, TDS and Temperature) on fruit yield in NFT cultivated *C. annum* plants over a 7-week growth period.

DAT (Weeks)	EC	pH	TDS (ppm)	Temp (°C)	No. of. Fruits
DAT 49 (7 th Week)	1980	5.1	960	27.5	7.86±2.5
DAT 56 (8 th Week)	1910	5.1	920	26.1	16.46±4.4
DAT 63 (9 th Week)	1820	5.2	900	25	31.9±5.84
DAT 70 (10 th Week)	1890	5	910	28.1	42±4.8
DAT 77 (11 th Week)	1960	4.8	935	29	55.6±3.4
DAT 84 (12 th Week)	2100	4.7	1050	29	64.86±6.9
DAT 91 (13 th Week)	2430	4.8	1280	28.6	70.4±1.8

Note: Number of replicates maintained (n=15).

Table 4: Pearson correlation analysis among EC, pH, TDS temperature of nutrient solution and no. of chili fruits.

Parameters	EC	pH	TDS (ppm)	Temp (°C)	No. of. Fruits
EC	1	-0.65	0.99	0.57	0.64
pH	-0.65	1	-0.59	-0.90	-0.86
TDS (ppm)	0.99	-0.59	1	0.48	0.65
Temp (°C)	0.57	-0.90	0.48	1	0.67
No. of. Fruits	0.64	-0.86	0.65	0.67	1

According to the Pearson correlation analysis, there is a positive correlation between the number of chili fruits and nutrient solution parameters EC, TDS and temperature is consistent with the findings, where the salinity levels in the NS reduced the stress impact in producing tomatoes (Suhandy, 2014; Costan *et al.*, 2020). But a negative correlation coefficient between pH and fruit number aligns with the findings, reported by Islam *et al.*, (2010); Kudirka *et al.*, (2023) indicates a weak relation between the pH of NS to the production of fruits. A significant correlation between the EC and TDS, observed in the current study as the EC and TDS values changes correspondingly, is consistent with the previous reports by Thirumalini and Joseph (2009) using regression analysis. The weakest relationship is shown by the pH followed by temperature with other parameters indicating there is no remarkable action caused by them in the overall system.

CONCLUSION

Overall, the results of this study provide a comprehensive understanding on growing chilies, in NFT hydroponics efficiently and effectively eliminating the spraying of harmful chemical substances. The results concerning significant growth in shoot length, root length, number of leaves and nodes over time lay out a detailed overview of the cultivation which could be useful for enhancing plant growth in NFT hydroponic systems. These findings have important implications for sustainable and efficient chili production, irrespective of the seasonal changes and suggest that NFT hydroponics can be a viable method for chili production without usage of pesticides and may have potential for

scaling up to larger-scale commercial operations. Further studies could explore the commercial production of chilies using automated hydroponic systems with decreasing labour costs.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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