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Analysis of the Environmental Parameters of Hydroponic Crop Grown under Polyhouse Conditions in Different Seasons

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A study was conducted on Basil (*Ocimum Basilicum*) crop grown under Polyhouse hydroponics in different seasons by controlling the environmental parameters at Dr. NTR College of Agricultural Engineering, Bapatla. The research work conducted for four seasons i.e., Season1(April and May), Season2(August and September), Season3(October and November) and Season4(January to February) on environmental parameters is presented in this paper. The environmental parameters were tried to be controlled to maintain a proper relative humidity range, i.e., 60-75%, a temperature below 30 °C, and CO_2 levels of 600 to 1500 ppm. The controlled environment and observations recorded by using Rotronic CP11'for crop analysis purpose. This makes a good quality and

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disease-free crop production. The final results reveal that the highest yield of 41.7 kg in seaso, followed by 40.5 kg in season2, 38.9 kg in season3, and 36.2 kg in season4. The lowest yield of all the seasons was 36.2 kg in season4. Ultimately, the experiment showed that the basil crop grows in good health throughout Season1 and then again during Season2. Polynomial equations were fitted for the humidity and temperatures maintained inside the hydroponic polyhouse which are discussed in this paper. R^2 values between 0.5 and 0.7 were obtained for all the fitted equations. According to the study, yield has a positively correlated with temperature and negatively correlated with relative humidity and carbon dioxide.

Keywords: Hydroponics; environmental parameters; rotronic CP11; polynomial equation.

1. INTRODUCTION

"Throughout the world, 50% of the arable land is unsuitable for farming activities (United Nation, 2017) and per capita surface water availability declined from 5260 cubic meter per year in 1951 to around 1000 cubic meter in 2016. India's population is estimated as 1.37 billion (18% of the world population) having only 2.4% of the world's geographical area and 4% of world's fresh water out of which 80% is used for agricultural operations. The decline of natural resources and increase in population necessitates the need to improve agricultural productivity for the growing population. This cannot be achieved by the available traditional farming techniques" (United Nation, 2017).

"Soil is the essential medium for the growing of plants. It provides the water, air and nutrients etc. for the successful growth of plant. However, soil do pose severe limitations for the plant growth, some times. Another serious problem is the difficulty to hire labor for conventional open field agriculture. In conventional soil method, most of the water provided to the crops is leached deep into the soil and is inaccessible to the roots of the crops. In this method, the farmer has to go to farm regularly to check and measure environmental parameters (Kumar and Cho, 2014), which require an enormous amount of hard work and attention, some negligence, can also result in poor quality and low productivity" (Asolkar and Bhadade, 2015). In view of these reasons, to overcome this shortfall in the yield, the world requires to invent techniques to improve and increase the productivity of farming systems i.e., soil less culture.

"The soil-less culture is mainly referred to the technique of Hydroponics. This technique means the growing of plants in nutrient solutions without use of soil. The plants are grown with their roots in the mineral nutrient solution only or in an inert medium, such as cocopeat, perlite and vermiculite etc. Plants grown in the hydroponic system can achieve 20-25% higher yields than a soil-based system with productivity 2-5 times higher" (United Nation, 2017).

"Generally, the hydroponic cultivation was adapted in closed or protected structures such as polyhouses. The protected structures provide controlled environment for the crop growth. This protects the crop from harsh external climatic conditions. Controlled environment agriculture (CEA) supplements crop production and quality by protecting the crops from pest, diseases and maintaining growing conditions" (Niu and Masani, 2018).

The environment inside a polyhouse consists of different parameters that build the inside microclimate. These are called as microclimatic parmeters and are termed as solar radiation, temperature distribution (Sauser et al., 1998), relative humidity and carbon dioxide concentration. It is necessary to analyze the climatic parameters to evaluate the climate suitability in a region for crop growth under protected cultivation. The other climate parameters such as soil temperature in relation to air temperature, wind, rainfall and air composition, influence to a lesser degree. Carbon dioxide (CO_2) and photosynthetically active radiation (PAR) accumulated over the day, are also two primary variables which affect the plant growth in a greenhouse. Water vapor pressure deficit (VPD) between greenhouse air and crop may affect the transpiration and consequently absolute air humidity. These parameters are mostly responsible for the development of plants and play an important role in quality and productivity.

In the present study, an attempt was made to understand the effect of environmental parameters on a hydroponically grown crop inside a naturally ventilated polyhouse. The crop considered for the study was Basil. Sweet basil

(Ocimum basilicum) is an annual plant of the Lamiaceae family. It is a small bushy plant of about 600 mm in height and is grown for its aromatic properties, while the green leaves are used fresh or dried for flavouring of dishes, salads, stews, sausages and other food (Niederwireser 2001). The curative properties of basil result from the presence of essential oils, phenolic compounds, flavonoids (Nurzyńska-Wierdak et al., 2012) and other substances revealing anti-bacterial (Nour et al., 2009), anti-mycotic (Oxenham et al., 2005) and antioxidant activities (Sekar et al., 2009; Taie et al., 2010).

2. MATERIALS AND METHODS

The current research was carried out in a naturally ventilated polyhouse constructed at the Dr. NTR College of Agricultural Engineering, Bapatla, with dimensions of 20 m x 12 m was used in the present study. Naturally ventilated polyhouse is best suited at places where it is neither too hot nor too cold. Here there are openings in the sides that can be closed or opened to let in cold air, and the warm air goes out.

2.1 Control the Environmental Parameters

Throughout the experiment, suitable instruments, such as foggers and dehumidifiers, must be used to regulate and control the environmental parameters in a hydroponics structure. Optimum temperature and humidity are required for proper growth of the basil crop.

2.2 Four-Way Foggers

Foggers were used to maintain the temperature and relative humidity inside the poly house (Rani, R.S. et al., 2022). Each nozzle has 4-way foggers with a flow rate of 4 L/h at an operating pressure range of 3.12 to 4.21 kg/cm^2. The average droplet size of the fogger is fine fog of 65 microns and connected to 1 hp motor. This created a favourable saturated humidity ideal for cropping. 4-Way hanging fogger assembly complete with anti-drip valve was shown in Fig. 2.

2.3 Dehumidifier

As seen in Fig. 3, a dehumidifier was placed on the table at the front of the polyhouse to remove hot air from the structure and produce a comfortable atmosphere that met the requirements of the crop (Rani, R.S. et al., 2022).

2.4 Measurement of Environmental Parameters

The Rotronic CP11 handheld instrument (Fig. 4) is the latest development of an economical multiple parameter which simultaneously measures and records the environmental parameters like CO_2, humidity and temperature in polyhouse daily in 1 h intervel (Rani, R.S. et al., 2022). The data were used for observing daily variation in microclimate during the experiment. Data from the Rotronic CP11 Instrument can be downloaded using the SW21 software shown Fig. 5.

"Download" to download the recorded data to the PC. Data cannot be downloaded while the CP11 is in the process of recording data. Stop data recording from the CP11 keypad prior to downloading data. SW21 automatically opens the data file in Chart View shown Fig. 6.

Fig. 1. Study area

Fig.2. Four-way foggers

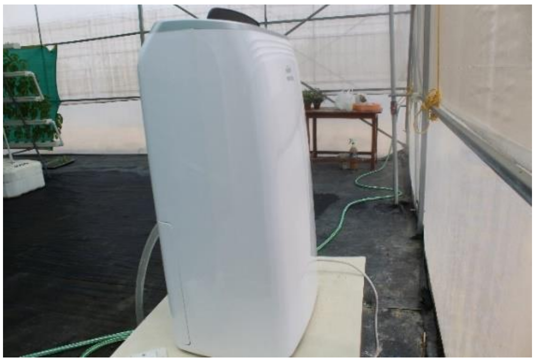


Fig. 3. Dehumidifier used inside polyhouse

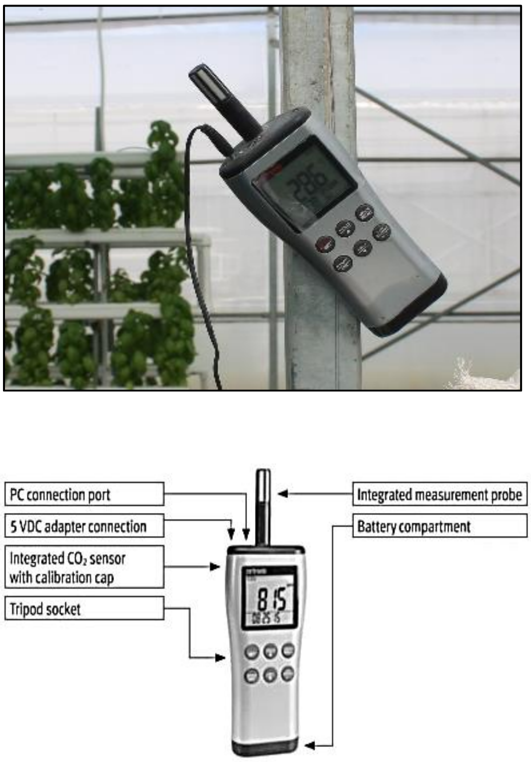


Fig. 4. Rotronic CP11 instrument

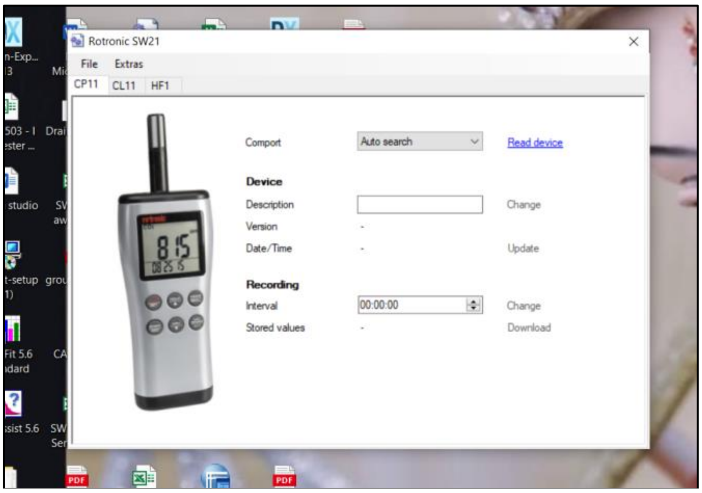
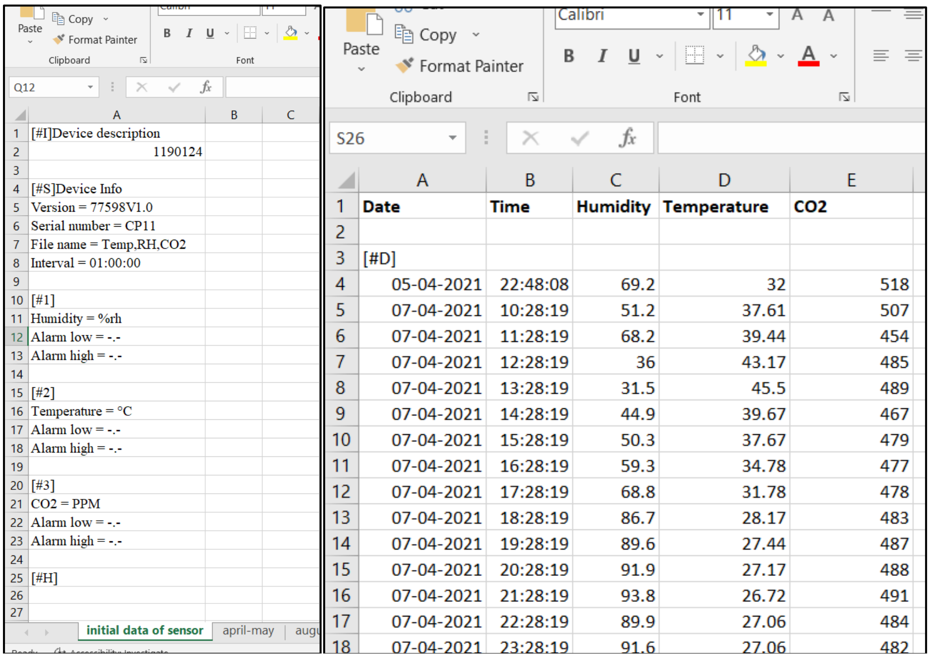


Fig. 5 Window of Rotronic SW21 software after open



	A	B	C
1	[#I]Device description		
2	1190124		
3			
4	[#S]Device Info		
5	Version = 77598V1.0		
6	Serial number = CP11		
7	File name = Temp,RH,CO2		
8	Interval = 01:00:00		
9			
10	[#1]		
11	Humidity = %rh		
12	Alarm low = -.-		
13	Alarm high = -.-		
14			
15	[#2]		
16	Temperature = °C		
17	Alarm low = -.-		
18	Alarm high = -.-		
19			
20	[#3]		
21	CO2 = PPM		
22	Alarm low = -.-		
23	Alarm high = -.-		
24			
25	[#H]		
26			
27			

	A	B	C	D	E
1	Date	Time	Humidity	Temperature	CO2
2					
3	[#D]				
4	05-04-2021	22:48:08	69.2	32	518
5	07-04-2021	10:28:19	51.2	37.61	507
6	07-04-2021	11:28:19	68.2	39.44	454
7	07-04-2021	12:28:19	36	43.17	485
8	07-04-2021	13:28:19	31.5	45.5	489
9	07-04-2021	14:28:19	44.9	39.67	467
10	07-04-2021	15:28:19	50.3	37.67	479
11	07-04-2021	16:28:19	59.3	34.78	477
12	07-04-2021	17:28:19	68.8	31.78	478
13	07-04-2021	18:28:19	86.7	28.17	483
14	07-04-2021	19:28:19	89.6	27.44	487
15	07-04-2021	20:28:19	91.9	27.17	488
16	07-04-2021	21:28:19	93.8	26.72	491
17	07-04-2021	22:28:19	89.9	27.06	484
18	07-04-2021	23:28:19	91.6	27.06	482

Fig. 6. Details of intrument downloaded data

3. RESULTS AND DISCUSSION

3.1 Temperature

The temperature is the inverse function of the relative humidity and directly proportional to the CO_2 concentration. The overall scenario of temperature maintenance, A polynomial equation was tried to fit for the patten against calender days for all the seasons. With an R^2 =0.75, equation could represent the temperature pattern which was maintained inside the greenhouse shown in Fig. 7.

The best temperature range for basil is between 80 to 90 degrees Fahrenheit (about 27 to 32 °C), with six to eight hours of direct sunlight every day. Temperature influences the rate of development and as a result of lower average daily air temperature, flowering is often delayed when plants are grown at cooler temperatures. Extremely low or high temperature can cause damage, reducing yields and/ or making shoots unmarketable. Increasing or decreasing the difference between day and night air temperature can increase or decrease stem and internode elongation.

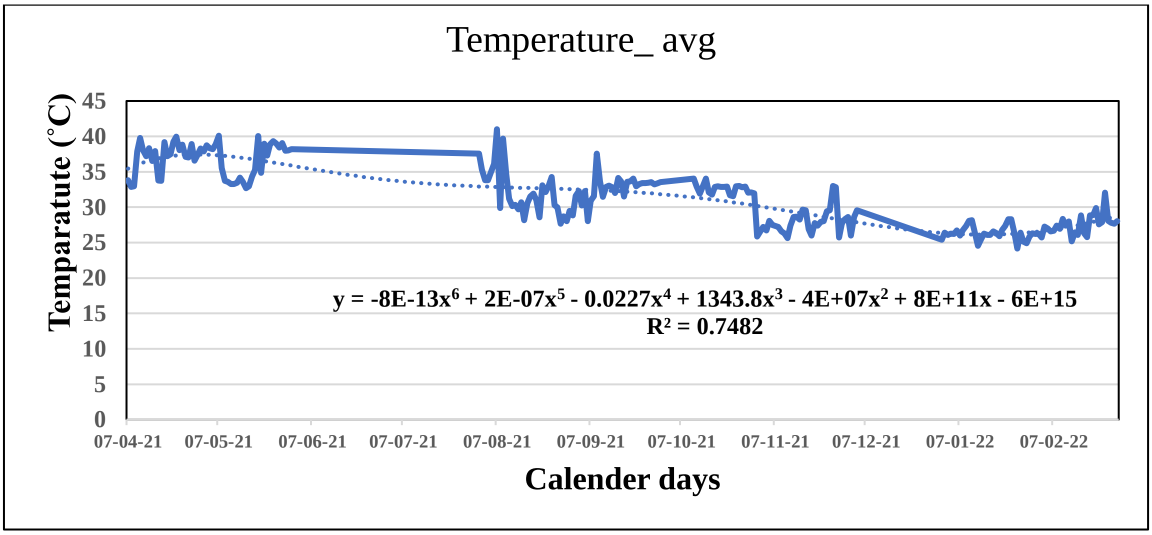


Fig. 7. Variation of temperature in polyhouse in four seasons

3.2 Relative Humidity

Relative Humidity is important to make photosynthesis possible. In the case of basil, good humidity around the plant is even more important than for most other crops, because the plant can only absorb a reduced amount of humidity and hence has less water evaporation than most plants. If the plant loses too much water, the stomata will close with the result that photosynthesis stops. If this happens, no further CO_2 can be absorbed, and CO_2 is required to keep the photosynthesis going.

The overall scenario of relative humidity maintenance as shown in Fig. 8, A polynomial equation was tried to fit for the patten against calender days for all the seasons. A value of R^2 =0.6 was observed for the fitted polynomial equation of order 6.

“Basil plants will operate without damage with relative humidity ranging from 65-70%. Lower relative humidity can stress the plants by allowing them to spend excessive energy pumping water through their tissue into the air. Rapid changes in the relative humidity can severely stress a plant. A relative humidity increases or decrease of as little as 20 per cent in a few minutes can cause tissue damage because the plant cannot adapt quickly enough. Rapid decreases in relative humidity can be brought about by suddenly bringing in large volumes of dry outside air for polyhouse cooling purposes. A drop in polyhouse temperature due to nightfall or sudden cloud cover can quickly bring about an increase in relative humidity. If the plant has been rapidly taking up water, it will continue doing so because any adjustment in plant water uptake occurs slowly (United Nation, 2017). The water taken up after the rise in relative humidity cannot be given off as freely into the air through the leaves and instead may be stuffed into foliage to an extent that it does cell damage. Basil plant can also experience rapid increases and decreases in relative humidity because of temperature changes and cooling system air exchanges in the polyhouse. Either the rapid increase or the rapid decrease in relative humidity can cause leaf tissue damage in basil plant.

3.3 Carbon Dioxide (CO_2)

Polyhouse need to be properly sealed to maintain a desirable level of CO_2. Excess CO_2 level can be toxic to plants. On warmer days, it is difficult to maintain desirable higher CO_2 levels because of venting to cool the polyhouses. The most common way to increase the CO_2 concentration in the polyhouse is by making use of the exhaust gases from the cogeneration. These exhaust gases contain a significant concentration of CO_2. However, they also contain the harmful gases NOx and Ethylene.

The overall scenario of CO_2 maintenance, A polynomial equation was tried to fit for the pattern against calender days for all the seasons. With an R^2 =0.7, equation could represent the CO_2 pattern which was maintained inside the greenhouse as shown in Fig. 9.

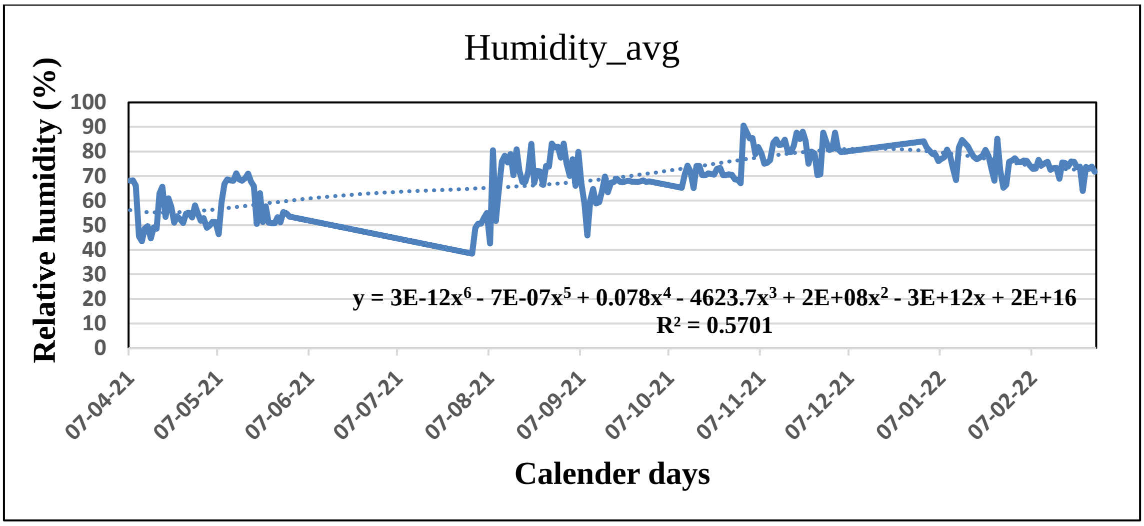


Fig. 8. Variation of relative humidity in polyhouse in four seasons

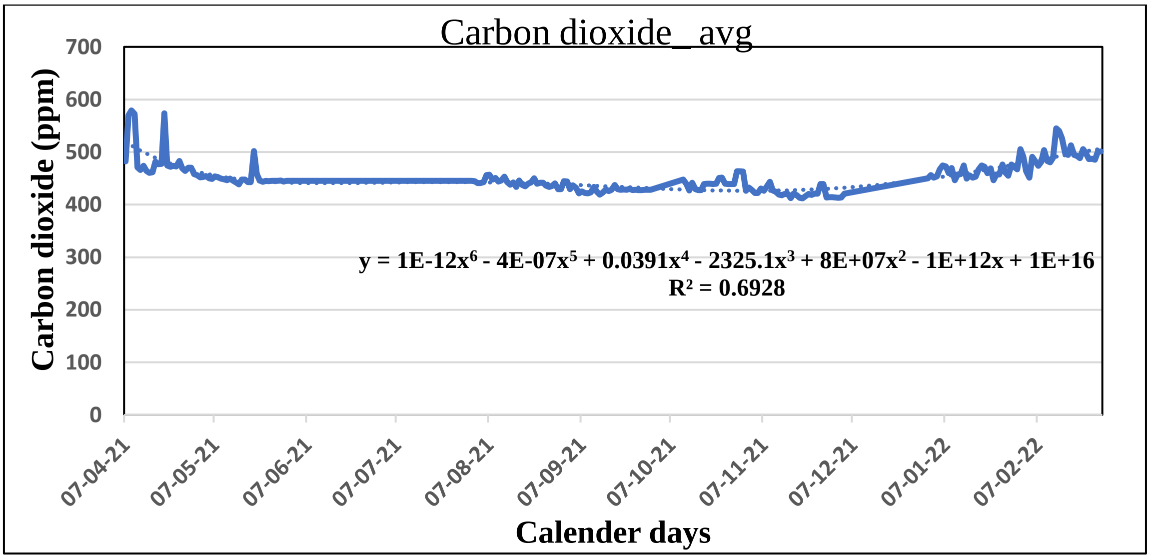


Fig. 9. Variation of CO_2 concentration in polyhouse in four seasons

3.4 Yield of Basil Crop in Four Seasons

The yield of basil was influenced significantly due to different seasons. Yield influenced by different seasons is graphically represented as shown in Fig. 10. The results showed that the yield of basil plants, as measured by fresh weight, was significantly different between seasons.

The yield of basil grown in different seasons of season1, season2, season3 and season4 is shown in Fig. 10. The crop was harvested two times at each season, the crop was weighed and noted down the weight of the crop. The highest yield observed in season1 as 41.7 kg, followed in season2 as 40.5 kg, season3 as 38.9 kg and season4 as 36.2 kg. Among all the seasons lowest yield was observed in season4 as 36.2 kg. The total yield of basil is 157.3 kg. Finally, the experiment showed that the basil crop grows in good health throughout Season1 and then again during Season 2.

The ideal temperature was maintained within the polyhouse, the season1 produced the maximum yield when compared to the other seasons.

In season 4 the growth was observed to slow down in the fall, winter and spring because the average daily temperature is getting lower in the polyhouse and the rate of new leaf appearance is decreasing. With the slower leaf unfolding rates,

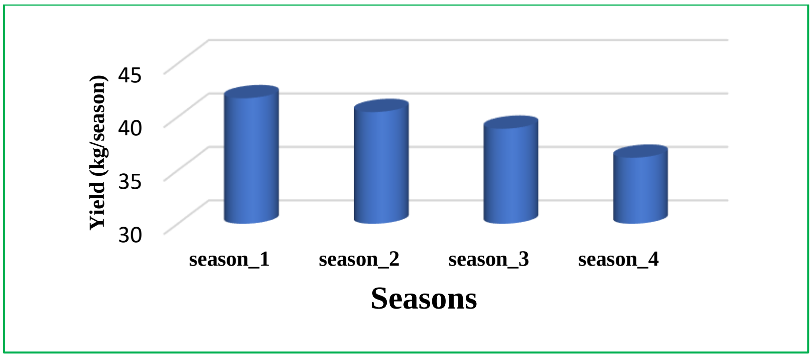


Fig. 10. Yield of Basil in different seasons

Table 1. Correlation between environmental parameters and yield

	Yield	T	RH	CO_2
Yield	1			
T	.602	1		
RH	-.433	-.940	1	
CO_2	-.405	.033	-.319	1

it takes longer for basil shoots to form enough leaves to become harvestable. While polyhouse air temperature set points for heating and cooling may have not changed throughout the year, average daily temperatures may decrease for several reasons. First, with lower light intensities there is less radiant energy entering the polyhouse and increasing the air temperature. Additionally, plants will lose heat to the polyhouse superstructure and to clear night skies, which can result in plant temperatures below air temperatures.

3.5 Correlation between Environmental Parameters and Yield

The temperature, relative humidity and carbon dioxide were taken as independent variables, whereas the yield was taken as the dependent variable. The analysis was carried out for correlation between environmental parameters and yield and were presented in Table 1.

From the Table 1 it could be observed the interactions between various independent variables and depended variable i.e., yield. It could be seen that the yield is positively correlated with temperature and negatively correlated with relative humidity and carbon dioxide.

A mathematically developed multiple linear regression equation was presented below in equation 1.

$$Y = 0.193\ T + 0.030\ RH - 0.011\ CO_2 + 0.947 \quad (1)$$

Where,

Y = Yield (kg)
T = Temperature (˚C)
RH = Relative humidity (%)
CO_2 = Carbon dioxide (ppm).

4. CONCLUSION

The trend towards tunnel farming and hydroponic systems is increasing owing to the climatic changes as well as the need to increase crop yield. Tunnel farming and hydroponic system requires controlled environmental parameters like temperature, humidity and CO_2 for better production of crops. This paper presents the highest yield of 41.7 kg in season 1, followed by 40.5 kg in season 2, 38.9 kg in season 3, and 36.2 kg in season 4. The lowest yield of all the seasons was 36.2 kg in season 4, and the total yield of basil was 157.3 kg. To find out the variation trend of the above parameters, polynomial equations were fitted with order between 5 and 7. R^2 values between 0.5 and 0.7 were obtained for all the fitted equations. As per the study, it could be seen that the yield is positively correlated with temperature and negatively correlated with relative humidity and carbon dioxide. It can also be concluded that environmental factors have a huge impact on the quality of most of hydroponically cultivated crop. It was reported that the environmental factors not only affect the external and internal quality of the products, and physiological processes, but also lead to changes in appearance of products.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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