



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(6): 710-716
Received: 17-04-2026
Accepted: 23-05-2026

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Evaluation of broccoli performance in multiple growing environments: From traditional soil to advanced hydroponic systems

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6i.5774>

Abstract

Broccoli, derived from the Italian term *broccolo*, meaning “flowering crest,” was used in this study to compare soil and soilless cultivation systems and their influence on plant growth. The evaluation focused on variations in nutrient availability, pest incidence, and moisture regulation across the two systems. Results indicated that soilless cultivation provides a more controlled and efficient growing environment, whereas soil-based cultivation reflects the natural variability of field conditions. An experiment was conducted in 2025 at the School of Agricultural Sciences, Malla Reddy University, Hyderabad, to assess six treatments: Tower Model Hydroponics, NFT Hydroponics, Growing Media, FYM, and Soil. These treatments were arranged in an RBD design with four replications. Among all treatments, T₂ – NFT Hydroponics recorded the highest growth parameters, including plant height (70.75 cm), leaf length (42.00 cm), leaf width (24.76 cm), number of leaves (26.25), and plant spread (78.75 cm). The lowest growth was observed in T₆ – Soil, with plant height (54.26 cm), leaf length (32.75 cm), leaf width (19.75 cm), number of leaves (12.25), and plant spread (66.25 cm). Overall, T₂ – NFT Hydroponics outperformed all other treatments, achieving superior results across most growth parameters.

Keywords: Nutrient film technique, tower model hydroponics, broccoli, soil and soilless

1. Introduction

Broccoli (*Brassica oleracea* L. var. *italica*), a member of the Brassicaceae family, is a cool-season vegetable cultivated for its edible, immature flower heads. The name “broccoli” originates from the Italian word *broccolo*, meaning “the flowering crest of cabbage.” Native to the Mediterranean region, broccoli grows optimally at temperatures of 20–25 °C, with ideal head formation occurring between 15–20 °C (Thamburaj & Singh, 2001) [17]. It is commonly classified into three colour types—green, purple, and white—and although it resembles cauliflower, it differs in its inflorescence structure.

Consumption of broccoli has increased globally due to heightened health awareness, as it is rich in vitamins A and C, essential minerals such as calcium and iron, dietary fibre, and potent antioxidants. It also contains ascorbic acid, thiamine, riboflavin, niacin, and glucosinolates, compounds associated with anticancer properties. In India, broccoli is predominantly consumed fresh, whereas in Europe and the United States it is used in both fresh and frozen forms. Cooking methods such as steaming and microwaving help retain most nutrients, while boiling results in significant nutrient loss (Kumar *et al.*, 2024) [23]. Broccoli is cultivated in two major forms: heading broccoli, which produces a single compact head, and sprouting broccoli, which produces multiple smaller heads. As a heavy nutrient feeder, broccoli requires a well-balanced nutrient supply for optimal growth. However, soil-based cultivation often faces challenges such as nutrient variability, pest pressure, and environmental fluctuations, especially under open-field conditions. Consequently, interest in soilless cultivation methods has increased. Hydroponic systems, in particular, offer precise nutrient delivery and controlled growing environments, making them increasingly popular in protected agriculture. Additionally, broccoli contains nearly fourteen times more beta-carotene than cabbage (Minz *et al.*, 2023) [2], further establishing it as a highly nutritious vegetable.

Different cultivation systems offer unique advantages and limitations. Tower hydroponics utilizes vertically stacked units through which nutrient-rich water flows, enabling efficient space use and providing a clean, controlled environment with reduced soil-related issues. The Nutrient Film Technique (NFT) system supplies a thin, continuous film of nutrient solution to plant roots, ensuring excellent oxygenation, rapid nutrient uptake, and minimal plant stress, thus supporting fast and uniform growth. Sand cultivation provides excellent drainage and aeration but retains limited water and nutrients, necessitating frequent irrigation and fertilization. Growing media such as cocopeat and perlite offer better water retention and aeration compared to sand, creating a uniform and soil-free environment suitable for root development; however, nutrients must be supplied through fertigation. Farmyard manure (FYM) improves soil structure, fertility, and microbial activity by slowly releasing nutrients through organic decomposition, though its composition can be variable. Traditional soil cultivation provides natural anchorage, water, and nutrients but is often inconsistent in fertility and may harbour pests and diseases. This study aimed to evaluate the potential of different cultivation practices on the growth and performance of broccoli.

2. Literature Review

Broccoli (*Brassica oleracea* L. var. *italica*) is a nutrient-dense vegetable valued for its high content of vitamins, minerals, antioxidants and glucosinolates. Several studies emphasize broccoli's importance as a functional food, noting its high beta-carotene and phytochemical concentration compared to other Brassica crops [1, 2]. As a cool-season crop and heavy nutrient feeder, its growth and head quality are strongly influenced by nutrient availability, soil conditions and environmental stability. Soil-based broccoli production has been widely reported to face challenges such as nutrient variability, pest incidence, water imbalance and inconsistent soil structure [3]. Organic amendments like farmyard manure (FYM) improve soil fertility and microbial activity but exhibit variable nutrient release patterns that often limit precision-based cultivation [4]. Sand-based cultivation offers improved aeration and drainage but requires frequent fertigation due to poor nutrient-retention capacity [5].

In contrast, soilless cultivation systems have gained attention for enabling precise control over nutrient delivery, water supply, and root-zone environment. Hydroponic systems such as the Nutrient Film Technique (NFT) and vertical tower systems allow year-round production with greater uniformity and reduced soil-borne diseases [6, 7]. Several studies report that NFT-grown broccoli exhibits improved vegetative growth, better oxygenation of roots, faster nutrient uptake and higher uniformity in plant development when compared with soil-based cultivation [8]. Similarly, vertical/tower hydroponics has demonstrated efficient use of space and optimized resource utilization, making it suitable for urban and protected cultivation systems [9].

Comparative studies consistently show that hydroponically grown broccoli performs better in parameters such as plant height, leaf area, biomass accumulation, and sometimes head yield, although differences in nutrient composition may vary depending on cultivar and nutrient-solution formulation [10, 11]. Reviews also indicate that both hydroponic and soil systems can produce high-quality heads if nutrient regimes are optimized, but hydroponics generally results in faster growth cycles and reduced environmental stress [12]. Despite this, research gaps remain in simultaneous comparison of multiple soilless methods

(NFT, tower, media-based) against traditional soil within a single experimental design, especially under Indian agro-climatic conditions.

The existing literature therefore highlights the need for comprehensive evaluations of soil and soilless cultivation systems to determine their influence on broccoli growth and morphology. The present study addresses this gap by comparing six cultivation methods i.e., NFT hydroponics, tower hydroponics, growing media, FYM, sand/media variations and soil under a randomized block design to identify the most efficient system for broccoli production.

3. Proposed Materials and Methods

The present investigation was carried out during 2024–2025 at the Experimental Farm, Department of Horticulture, Malla Reddy University, Hyderabad. The experimental procedures followed and the materials used in this study are described below.

3.1 Treatment Details

Six cultivation systems were evaluated to compare the growth performance of broccoli under soil and soilless conditions. The treatments were as follows:

Table 1: Treatment details

Treatments	Components
T ₁	Tower Model Hydroponics
T ₂	NFT Model Hydroponics
T ₃	Sand
T ₄	Growing Media
T ₅	FYM
T ₆	Soil

3.2 Experimental Design

The experiment was laid out using a Randomized Block Design (RBD), which is one of the most commonly used designs in agricultural research. This design was selected because it effectively controls the variability that naturally occurs in the field. In open-field and semi-controlled environments, factors such as soil fertility, moisture levels, temperature variation, or microclimatic differences can influence plant growth. RBD minimizes the impact of such variability by dividing the field into homogeneous blocks, ensuring that each block experiences similar environmental conditions. Each of the six treatments (T₁–T₆) was included once in each block, and the blocks were replicated four times, resulting in a total of 24 experimental units. Within every block, the six treatments were assigned randomly to avoid bias and to ensure that differences in plant performance are due to treatments alone and not to positional effects.

The RBD structure therefore helped achieve

- Better precision by reducing experimental error
- Fair comparison among treatments
- Statistically reliable conclusions

Thus, the use of RBD was appropriate for this study because it accounts for natural field variability while ensuring that treatment effects are rigorously compared.

3.3 Statistical Analysis

The data collected from all growth and yield parameters were analyzed using Analysis of Variance (ANOVA), a statistical method used to determine whether significant differences exist

among the treatment means. ANOVA is suitable for multi-treatment experiments arranged in RBD because it partitions the total variation observed in the data into:

Treatment Variation – differences caused by the effect of the six cultivation systems

Block Variation – differences arising from environmental or site-based variability among blocks

Error (Residual) Variation – random or unexplained variation

After partitioning the variation, ANOVA tests whether the treatment effects are statistically significant using the F-test. If the calculated F-value exceeds the tabulated F-value at a chosen probability level (usually 5% or 1%), the differences among treatments are considered significant.

When significant differences were detected, further statistical tests such as Critical Difference (CD) or Least Significant Difference (LSD) were used to compare individual treatment means. This enabled the identification of which treatments performed better or worse relative to others.

The statistical analysis ensured

- Accurate comparison of the six cultivation methods
- Objectivity in interpreting the results
- Scientific validity of the conclusions drawn



Fig 1: Broccoli in Tower Model



Fig 2: Broccoli in Growing Media



Fig 3: Broccoli in Nft Model

4. Results and Discussion

Table 1: Effect of Different Substrates and Hydroponic Systems on plant height (cm) in broccoli

Treatment Details		Plant height (cm)		
		30 DAT	45 DAT	60 DAT
T ₁	Tower Model Hydroponics	19.00	29.19	60.00
T ₂	NFT Model Hydroponics	31.50	56.00	70.75
T ₃	Sand	23.75	51.25	64.75
T ₄	Growing Media	25.50	39.75	55.25
T ₅	FYM	27.00	51.00	54.75
T ₆	Soil	27.33	40.50	54.26
SEm (+)		0.98	1.05	0.49
CD (p=0.05)		2.98	3.21	1.50

Plant height is an indicator for evaluating plant growth, reflecting the ability to synthesize and accumulate organic matter. This was done by stretching the leaves upward and then measuring using a standard ruler from 5 plants at 30, 45 and 60 days after transplanting. At all the growth stages, the maximum plant height was recorded in treatment (T₂) NFT Model with obtain values 31.50, 56.00 and 70.75) cm Whereas, the minimum plant height was recorded from (T₁) Pine apple tower with given values (19.00, 21.19 and 60.00) cm. Plants grown in the NFT system show greater height because they receive a steady, well-balanced flow of nutrients that supports fast and uninterrupted stem growth. The roots stay highly oxygenated, helping the plant absorb nutrients efficiently and maintain active growth. Moisture remains constant, so the plants never face stress that could slow vertical development. With this stable environment, the plants stay healthy and physiologically active throughout the period. As a result, NFT plants grow taller and more vigorously than those in other systems. (Mohamed A., *et al.*, 2023) ^[16].

In the tower model, plant height is comparatively lower because nutrient distribution differs across levels, leaving some plants with less consistent nourishment. The limited root space restricts nutrient absorption, slowing overall stem growth. Moisture can fluctuate due to the vertical design, creating brief stress periods that interrupt vertical elongation. Light availability also varies across the tower, reducing photosynthesis in some positions. Together, these challenges lead to shorter plants in the tower system.

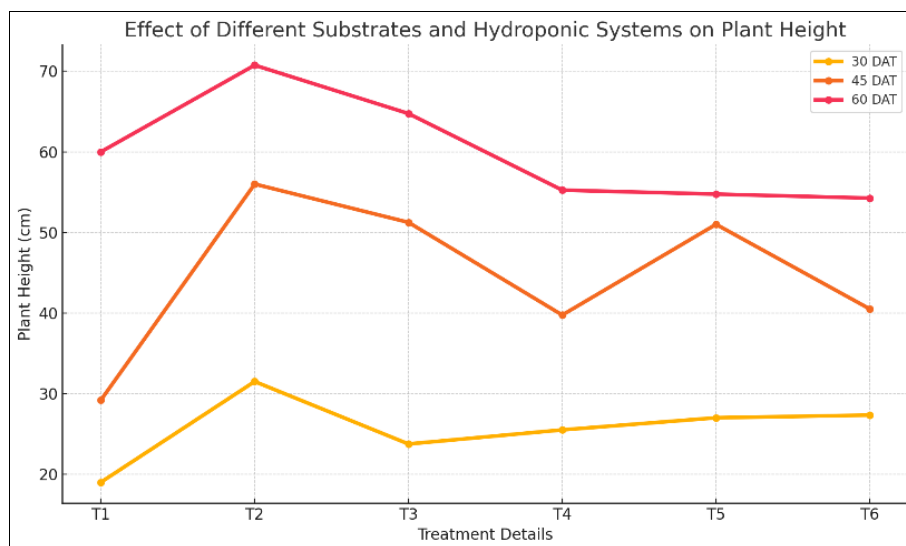


Fig 4: Effect of Different Substrates and Hydroponic Systems on Plant Height

The line chart shows plant height across treatments (T₁–T₆) at 30, 45 and 60 DAT, with T₂ (NFT) consistently attaining the greatest heights and T₁ (tower) and T₆ (soil) showing lower performance. Overall, plant height increases from 30 to 60 DAT for all treatments, with the steepest growth observed in T₂ between 30–45 DAT and sustained gains up to 60 DAT.

Table 2: Effect of Different Substrates and Hydroponic Systems on Leaf Length (cm) in broccoli

Treatment Details		Leaf Length (cm)		
		30 DAT	45 DAT	60 DAT
T ₁	Tower Model Hydroponics	16.00	31.25	40.62
T ₂	NFT Model Hydroponics	18.00	36.50	42.00
T ₃	Sand	13.50	31.50	35.25
T ₄	Growing Media	15.25	29.25	33.25
T ₅	FYM	14.00	31.75	33.75
T ₆	Soil	12.50	30.50	32.75
S.Em (±)		1.06	0.91	0.55
CD (p=0.05)		3.25	2.78	1.70

The results obtained for the leaf length varies for each treatment. Leaf length was measured using a standard ruler from 5 plants at 30, 45 and 60 days after transplanting. The maximum leaf length was obtained in (T₂) NFT Model Hydroponics (18.00, 36.50 and 42.00) cm. The minimum leaf length was observed in (T₆) soil (12.50, 30.50 and 32.75) cm. Leaf length was maximum in NFT because the system provides a continuous supply of nutrients that promotes rapid cell elongation. High oxygen availability at the roots enhances metabolic processes responsible for leaf growth. Uniform moisture prevents stress and supports uninterrupted leaf development. Nutrients are absorbed efficiently, allowing longer leaf formation. These ideal growing conditions naturally result in maximum leaf length in NFT. Leaf length was minimum in soil because nutrient availability is slow and inconsistent, restricting elongated leaf growth. Poor aeration reduces root activity, limiting the plant's ability to support long leaves. Moisture fluctuations often cause stress, slowing leaf expansion. Soil also has nutrient fixation and losses, reducing availability for growth. These limitations lead to shorter leaf length in soil-grown plants.

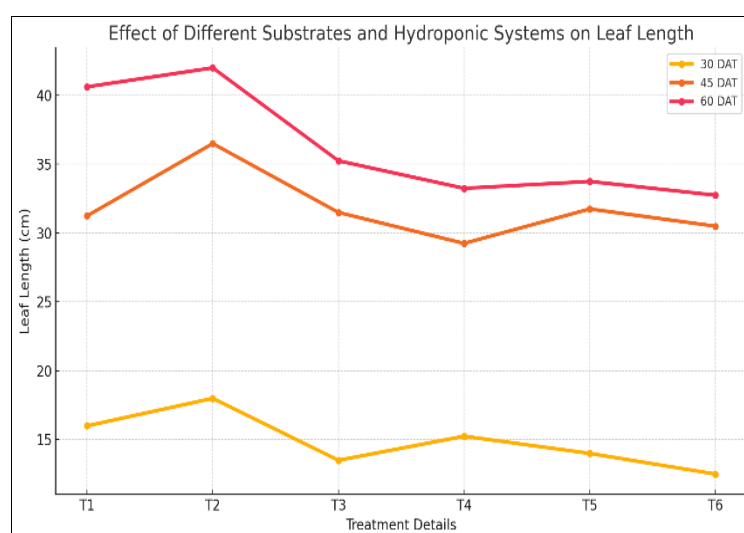


Fig 5: Effect of Different Substrates and Hydroponic Systems on Leaf Length

The line chart shows that leaf length increases across all treatments from 30 to 60 DAT, with T₂ (NFT Hydroponics) consistently producing the longest leaves at all stages. Soil and sand treatments exhibited the shortest leaf lengths, indicating slower vegetative growth under conventional and low-nutrient substrates.

Table 3: Effect of Different Substrates and Hydroponic Systems on Leaf Width (cm) in broccoli

Treatment Details		Leaf width (cm)		
		30 DAT	45 DAT	60 DAT
T ₁	Tower Model Hydroponics	7.83	17.25	19.68
T ₂	NFT Model Hydroponics	10.00	20.55	24.76
T ₃	Sand	7.50	14.00	20.50
T ₄	Growing Media	7.30	18.00	22.50
T ₅	FYM	7.50	15.50	21.42
T ₆	Soil	7.20	14.48	19.75
S.Em (±)		0.58	1.0	0.73
CD (p=0.05)		1.75	3.01	2.22

As broccoli grown in different soil and soilless media shows the statistically significant variation for leaf width of broccoli at 30, 45 and 60 days after transplanting. The maximum leaf length was recorded in (T₂) NFT Model with obtain values (10.00, 20.55 and 24.76) cm. Whereas, the minimum plant height was recorded from (T₄) Growing media with given values (7.20, 14.48 and 21.42) cm. Leaf width is greater in NFT because the continuous flow of nutrient-rich solution supports optimal cell expansion across the leaf surface. High oxygen availability in the root zone enhances metabolic activity, enabling broader leaf formation. Consistent moisture levels prevent water stress, allowing leaves to expand fully. Nutrients are absorbed efficiently and evenly, promoting uniform leaf development.

The stable environment minimizes fluctuations that could restrict leaf widening. (Mohamed A., *et al.*, 2023) [16]. As a result, NFT-grown plants develop wider and healthier leaves. Leaf width was lowest in soil because nutrients are inconsistently available, limiting lateral cell growth. Poor soil aeration restricts metabolic processes needed for broad leaves. Moisture fluctuations cause stress that prevents full leaf expansion. Nutrient losses from leaching reduce the support needed for widening. Soil-grown plants also face compaction, making nutrient uptake slower. These stresses reduce overall leaf development. Consequently, leaf width remains narrow in soil.

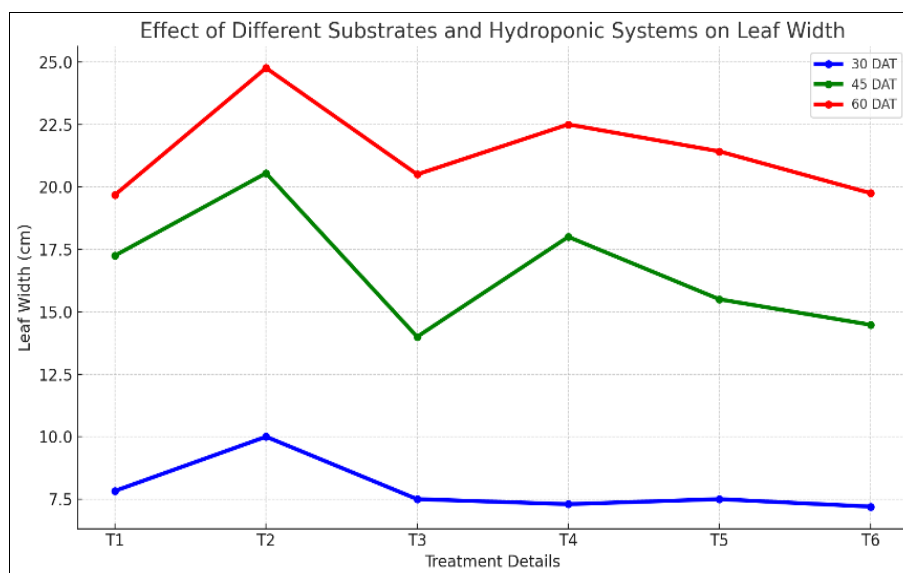


Fig 6: Effect of Different Substrates and Hydroponic Systems on Leaf Width

The line chart shows that leaf width increased across all treatments from 30 to 60 DAT, with T₂ (NFT) consistently producing the widest leaves due to continuous nutrient and oxygen supply. Soil and sand treatments recorded the lowest values, reflecting limited nutrient availability and slower leaf expansion.

Table 4: Effect of Different Substrates and Hydroponic Systems on No. of Leaves/ plant (cm) in broccoli

Treatment Details		No. of Leaves/ plant (cm)		
		30 DAT	45 DAT	60 DAT
T ₁	Tower Model Hydroponics	9.50	20.25	20.25
T ₂	NFT Model Hydroponics	11.75	19.75	26.25
T ₃	Sand	7.25	13.50	17.00
T ₄	Growing Media	7.0	11.75	14.75
T ₅	FYM	6.50	15.00	15.25
T ₆	Soil	6.50	12.75	12.25
S.Em (±)		0.47	0.99	1.01
CD (p=0.05)		1.42	2.98	2.17

From the about table 4, it can conclude that No. of Leaves was recorded at 30, 45 and 60 days of intervals all the treatments give various results. The maximum No. of Leaves was observed in T₂ – NFT (11.75, 19.75 and 26.25) and minimum in T₆ – soil (6.50, 12.75 and 12.25). The number of leaves was highest in NFT because plants continuously received easily available nutrients that encouraged fast and frequent leaf production. The roots stayed well-oxygenated, allowing them to generate more energy for growth. Moisture was always consistent, preventing

stress and supporting steady vegetative development. With minimal environmental fluctuations, the plants maintained an active metabolism throughout. This ideal growing environment helped NFT produce the maximum number of leaves. The number of leaves was lowest in soil because nutrient movement is slow and irregular, delaying new leaf formation. Poor aeration limits root efficiency, reducing the plant's ability to produce leaves quickly. Moisture fluctuations create stress that slows vegetative growth. Nutrient losses and deficiencies further restrict leaf development. Together, these factors cause soil-grown plants to produce the minimum number of leaves.

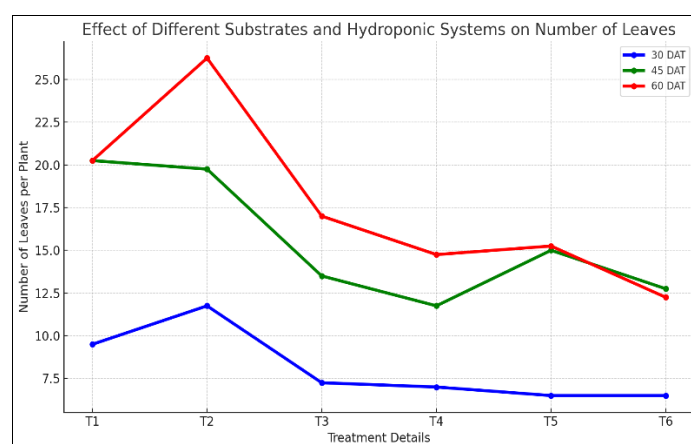


Fig 7: Effect of Different Substrates and Hydroponic Systems on Number of Leaves

The line chart shows that the number of leaves increases across treatments as plants mature, with T₂ (NFT Hydroponics) producing the highest leaf count at all stages due to continuous nutrient supply and optimal root aeration. Soil and growing media treatments consistently showed lower leaf numbers, indicating slower vegetative development under less efficient nutrient environments.

Table 5: Effect of Different Substrates and Hydroponic Systems on Plant spread(cm) in broccoli

Treatment Details		Plant spread(cm)		
		30 DAT	45 DAT	60 DAT
T ₁	Tower Model Hydroponics	31.25	41.50	60.75
T ₂	NFT Model Hydroponics	37.83	71.80	78.75
T ₃	Sand	26.50	54.75	65.25
T ₄	Growing Media	27.00	63.17	71.25
T ₅	FYM	27.90	42.75	64.00
T ₆	Soil	26.37	36.77	66.65
S.Em (±)		0.50	0.89	0.58
CD (p=0.05)		1.52	2.71	1.76

Plant spread was recorded in different treatments at 30, 45 and 60 days of intervals, the observed data shows variations for each treatment. The maximum plant spread was seen in T₂ – NFT (37.83, 71.80 and 78.75) cm and minimum in T₆ – soil (26.37, 36.77 and 66.65) cm. Plant spread was maximum in NFT because continuous nutrient availability encouraged strong lateral growth. High root oxygenation provided the energy needed for active branching and canopy expansion. Stable moisture levels ensured uniform growth in all directions. Plants experienced very little stress, allowing them to spread freely. (Mohamed A., *et al.*, 2023) [16]. This combination of favourable conditions resulted in the widest canopy in NFT. Plant spread was minimum in soil because poor aeration and slow nutrient movement limited lateral shoot development. Soil compaction restricted root expansion, reducing canopy width. Moisture variability created stress that slowed outward growth. Nutrient deficiencies further weakened branching. As a result, soil-grown plants showed the smallest overall plant spread.

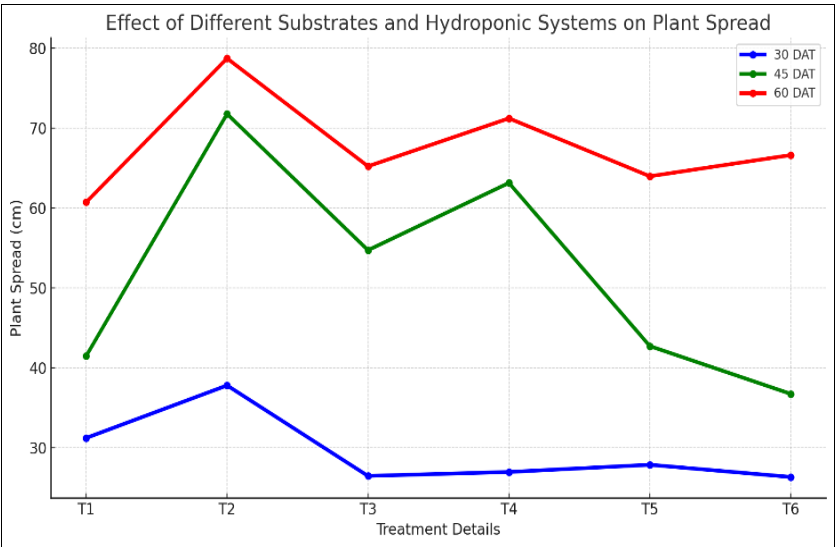


Fig 8: Effect of Different Substrates and Hydroponic Systems on Plant Spread

The chart shows that plant spread increased across all treatments over time, with T₂ (NFT Hydroponics) exhibiting the widest canopy at every stage due to optimal nutrient flow and aeration. Soil and sand treatments produced narrower plant spread, indicating slower lateral growth under less efficient nutrient conditions.

5. Conclusion

In this, proposed the different cultivation systems significantly influenced broccoli growth, with the NFT hydroponic system (T₂) consistently outperforming all other treatments. NFT recorded the highest plant height (70.75 cm), leaf length (42.00 cm), leaf width (24.76 cm), number of leaves (26.25) and plant spread (78.75 cm), indicating superior vegetative growth under continuous nutrient flow and optimal root aeration. In contrast, soil (T₆) produced the lowest values across most parameters, highlighting the limitations of conventional cultivation due to inconsistent nutrient and moisture availability. Overall, the results confirm that NFT hydroponics is the most efficient and productive method for broccoli cultivation under the conditions of this study, offering enhanced growth performance and greater potential for sustainable soilless production. Future work should focus on evaluating yield, head quality, and nutrient composition under optimized hydroponic conditions.

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