

Comparative Analysis of Leaf Area Index (LAI) for Selected Leafy Vegetables Cultivated in Soil and Hydroponics

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Received: 07 Jul 2025; Revised accepted: 25 Aug 2025

Abstract

Seven leafy vegetables species i.e. *Amaranthus viridis* L., *Trigonella foenum-graecum* L., *Corchorus olitorius* L., *Coriandrum sativum* L., *Mentha arvensis* L., *Cicer arietinum* L. and *Spinacea oleracea* L. were selected on the basis of their popularity and consumption among the people of central India. Data from soil-grown and hydroponic leafy vegetables were compared to measure the Leaf Area Index (LAI). Results showed that the LAI index in the soil-cultivated system for *C. arietinum* L. was 0.64 per ft², followed in increasing order by *M. arvensis* L. (1.02 per ft²), *T. foenum-graecum* L. (4.76 per ft²), *A. viridis* L. (4.44 per ft²), *C. olitorius* L. (6.39 per ft²), and *S. oleracea* L. (9.96 per ft²). The highest leaf area index was found in *C. sativum* L., which had a value of 12.49 per ft² among soil-grown leafy vegetables. On the other hand, in hydroponic systems, the value was lowest for *C. arietinum* L., at 0.64 per ft², followed by others in increasing order. *M. arvensis* L. (1.02 per ft²), *A. viridis* L. (4.44 per ft²), *C. olitorius* L. (5.73 per ft²), *T. foenum-graecum* L. (4.76 per ft²), and *S. oleracea* L. (12.82 per ft²). The highest LAI was recorded in *C. sativum* L. (15.95 per ft²). Comparative results significantly favor the hydroponic system.

Key words: Leafy vegetable, Consumption, Soil, Hydroponic, Leaf area index, High, Low, Favor

India's agriculture is crucial for its socioeconomic fabric, with high population density and growing demand for food and nutritional resources. Hydroponics is an innovative technique that offers advantages over traditional methods, reducing productivity costs [1-2]. However, it is not popular among farmers in most part of Indian Territory especially in central India, Chhattisgarh, a tribal state with a significant economy based on agricultural productivity and natural resources. Some varieties of green leafy vegetables are a major part of meals and are known for their medicinal value. Regular consumption of these vegetables helps avoid micronutrient deficiencies, which can lead to diseases like vision problems, skin health, cardiovascular disease, and hormonal balance [3]. Some plant species have the potential to control high blood pressure and diabetes, which are common among the people lives in village and urban areas [4].

There are many reasons for searching new technique and advancement in agriculture including India's high human population density and rapid population growth pose significant challenges to food security etc. Moreover, factors such as overexploitation, climate change, and global warming contribute to land loss, making food security a significant challenge [5-6]. Hydroponics, a simple and flexible plant cultivation technique, aims to support food security by encouraging people to cultivate plants at home, gardens, and offices [7]. However, hydroponics faces a lack of popularity, and researchers must identify the reasons behind this lack of awareness and make fresh efforts to address this issue.

Many growth parameters are available to compare feasibility of soil and hydroponic system. One of them is leaf area index (LAI), which is crucial for understanding agricultural processes, economic yields, and plant disease infestations [8]. However, its absolute value may not accurately predict biomass or production, as the total LAI can include various species, strategies, and behaviors. Seven species of selected plants are:

1. *Amaranthus viridis* L.: Green amaranth or Slender amaranth (Common name), *Amaranthus* (Genus), *Amaranthaceae* (Family), *Caryophyllales* (Order).
2. *Trigonella foenum-graecum* L.: Fenugreek (Common name), *Trigonella* (Genus), *Fabaceae* (Family), *Fabales* (Order).
3. *Corchorus olitorius* L.: Jute mallow (Common name), *Corchorus* (Genus), *Malvaceae* (Family), *Malvales* (Order).
4. *Coriandrum sativum* L.: Coriander (Common name), *Coriandrum* (Genus), *Apiaceae* (Family), *Apiales* (Order).
5. *Mentha arvensis* L.: Wild Mint (Common name), *Mentha* (Genus), *Lamiaceae* (Family), *Lamiales* (Order).
6. *Cicer arietinum* L.: Chickpea (Common name), *Cicer* (Genus), *Fabaceae* (Family), *Fabales* (Order).
7. *Spinacea oleracea* L.: Spinach (Common name), *Spinacia* (Genus), *Amaranthaceae* (Family), *Caryophyllales* (Order).

MATERIALS AND METHODS

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Citation: Prabhas L, Agrawal M, Ekka A. 2025. Comparative analysis of Leaf Area Index (LAI) for selected leafy vegetables cultivated in soil and hydroponics. *Res. Jr. Agril. Sci.* 16(4): 411-415.

Chhattisgarh, India, located in the states place category, has the latitude of 21.295132 and longitude of 81.828232, with GPS coordinates of 21° 17' 42.4752" N and 81° 49' 41.6352" E. It has a monsoon climate with three main seasons: summer (March to June), winter (November to February), and the rainy season (July to October).

Selection of leafy vegetables: Seven leafy vegetables species i.e. *Amaranthus viridis* L., *Trigonella foenum-graecum* L., *Corchorus olitorius* L., *Coriandrum sativum* L., *Mentha arvensis* L., *Cicer arietinum* L. and *Spinacea oleracea* L. were selected on the basis of their popularity and consumption among the people of central India. The study collected information through basic questionnaires and discussions with local healers, focusing on their diversity and medicinal value. The study also reviewed the physiological characteristics and life cycle of plants to determine their suitability for hydroponic

systems. Plant physiology plays a significant role in artificial plant cultivation methods.

Establishment of hydroponic system: Hydroponic systems are growing methods that use liquid nutrient solutions to support plant roots. They can be open or closed, and come in passive and active varieties. Nutrient management in closed systems is challenging, but four main techniques are used: automatic water addition, pH control, automatic holding tank water makeup, manual nutrient addition, batch nutrient refilling, and manual nutrient addition. Both indoor and outdoor establishment of hydroponic system is possible, depends upon the various factors like, available space, indoor and outdoor facility, type of plant to be cultivated, financial plan, environmental conditions etc. But most important factor is nutrient medium. There must be continuous and consistent supply of nutrient solution is required throughout the process.

Table 1 Composition of nutrient medium or Hoagland solution [9]

Component of nutrient solution	Chemical formula	Stock solution g/L	SS in 1 Liter of water	Type
Potassium nitrate	KNO ₃	202.00	2.5 ml	Macro element
Calcium nitrate	Ca(NO ₃) ₂	236.00	2.5 ml	Macro element
Fe (II) ethylenediaminetetraacetate (Fe-EDTA)	C ₁₀ H ₁₆ FeN ₄ O ₈	15.00	1.5 ml	Macro element
Magnesium sulphate	MgSO ₄	493.00	1 ml	Macro element
Boric acid	H ₃ BO ₃	2.86		Micro element
Manganese II chloride	MnCl ₂	1.81		Micro element
Zinc sulphate	ZnSO ₄	0.22		Micro element
Copper II sulphate	CuSO ₄	0.051		Micro element
Molybdcid acid	MoO ₃ H ₂ O	0.09		Micro element
Sodium molybdcid acid	Na ₂ MoO ₄	0.12		Micro element
Potassium phosphate	K ₃ PO ₄	136.00		Macro element

Serial dilution method has been applied for the preparation of micronutrient stock solution

Nutrient medium

Plant growth relies on sunlight and water, and nutrient solutions provide major and micro elements. Macronutrients include potassium, phosphorus, nitrogen, calcium, magnesium, and sulfur, while micronutrients include iron, chlorine, manganese, boron, copper, nickel, and molybdenum. Supplements like cobalt, selenium, silicon, iodine, sodium, and

vanadium may also be beneficial. Careful selection of optimum concentrations of micro- and macro-elements is crucial for optimal plant growth and maintenance of metabolic activities. There is a strong possibility of different nutritional requirement with different plant's species type. Hence, modification and changes are also quite possible as per requirement, as shown in (Table 1-2).

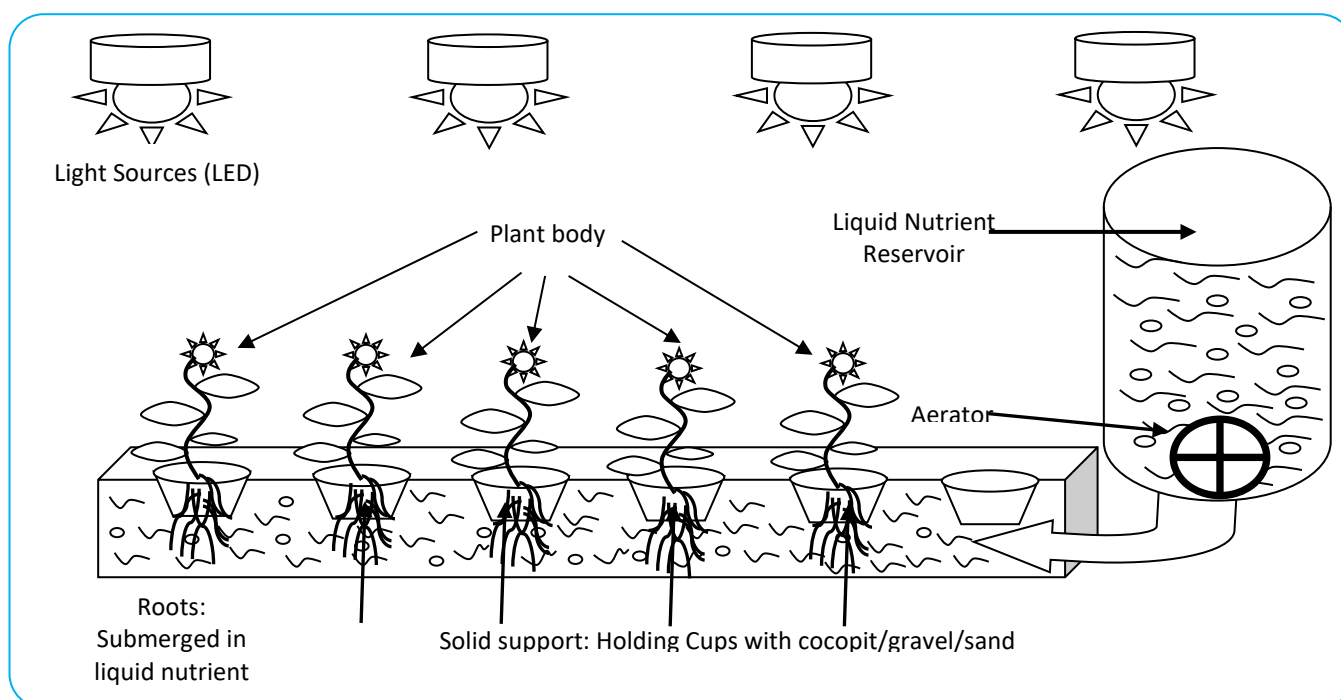


Fig 1 Nutrient film technique (Ebb and flow hydroponic system) [10]

RESULTS AND DISCUSSION

Measurement and calculation of leaf area index (LAI) for leafy vegetables

Observation of LAI in soil

The leaf area index of every plant species directly represents the photosynthesis assimilation efficiency (PAE) of the plant. The findings revealed that the LAI index for *Cicer arietinum* L. in the soil-cultivated system was 0.58 per ft², with *Mentha arvensis* L. (0.93 per ft²), *Trigonella foenum-graecum* (3.37 per ft²), *Amaranthus viridis* L. (4.09 per ft²), *Corchorus olitorius* L. (6.39 per ft²), and *Spinacia oleracea* L. (9.96 per ft²) following in ascending order [11-12]. Among soil-grown

green vegetables, *Coriandrum sativum* L. had the highest leaf area index (LAI) value (Table 1) (12.49 per ft²) [13].

Observation of LAI in hydroponics

Comparative results based on data obtained from both systems significantly favor the hydroponic system. The values obtained for LAI were higher for six leafy vegetable species cultivated in hydroponics: *C. arietinum* L. (0.64 per ft²), *M. arvensis* L. (1.02 per ft²), *A. viridis* L. (4.44 per ft²), *T. foenum-graecum* L. (4.76 per ft²), *S. oleracea* L. (12.82 per ft²), and *C. sativum* L. (15.95 per ft²). Only one leafy vegetable species, namely *C. olitorius* L. (5.73) was recorded with a lower value of LAI in the hydroponic system as compared to soil-cultivated leafy vegetable plants (Table 3) [14].

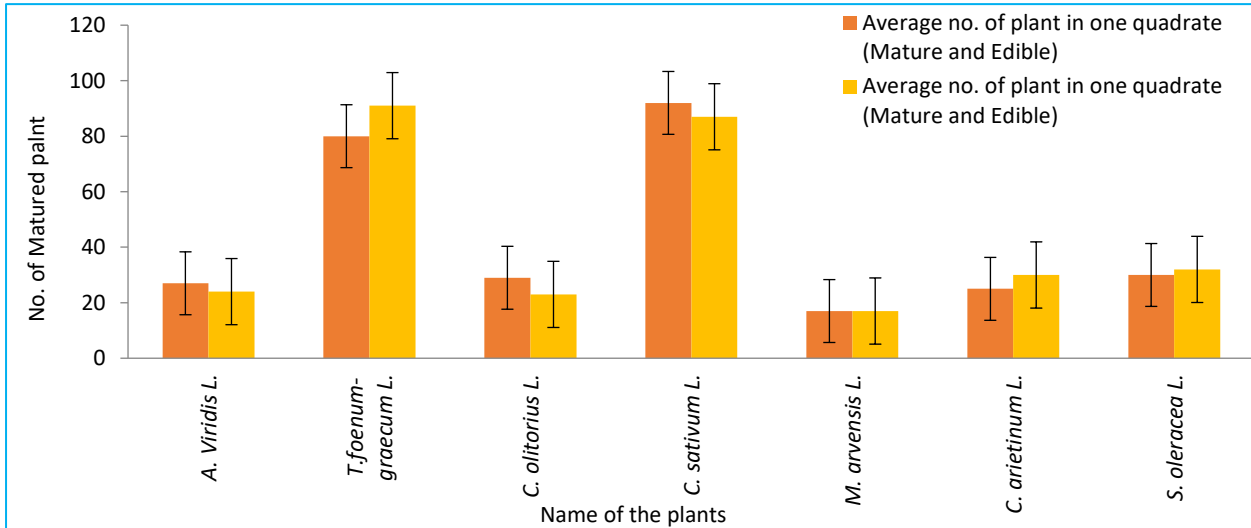


Fig 3 Showing leaf area index (LAI) of matured plants (leafy vegetables) obtained from soil and hydroponics

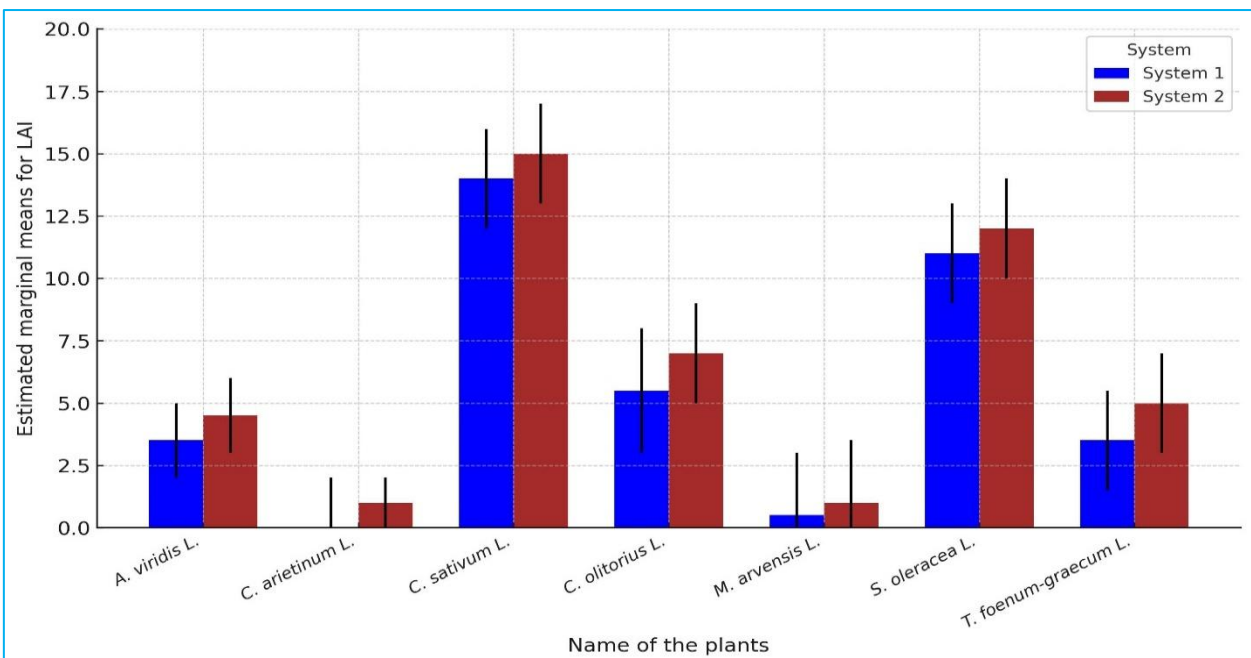


Fig 2 Showing average number of matured plants (leafy vegetables) obtained from soil and hydroponics

Statistical analysis

Experimental measurements were performed and expressed as the average \pm standard deviations for number of plants in total nine quadrates. MS Excel 2010 and SPSS software 26.0 were used to determine the magnitude of the means, standard curve, standard errors, and standard deviations (Table 2-3; Fig 2-3). All seven of the soil-grown leafy vegetable

plants — *A. viridis* L., *T. foenum-graecum* L., *C. olitorius* L., *C. sativum* L., *M. arvensis* L., *C. arietinum* L., and *S. oleracea* L.— had leaf area index (LAI) values of 4.09, 3.37, 6.39, 12.49, 0.93, 0.58, and 9.96 cm² feet⁻¹, respectively (Table 2). Nonetheless, the leafy vegetable species under investigation that were grown hydroponically had (LAI) values of 4.44, 4.76, 5.73, 15.95, 1.02, 0.64, and 12.82 cm² feet⁻¹ [15-16] (Table 3).

Descriptive analysis of the data obtained for LAI in soil and hydroponics reveals that values of the mean for the leafy vegetables cultivated in soil was 5.40 and 6.63 for hydroponics [17]. In a similar vein, the standard deviation values for the leafy crops grown in the same batch were 4.49 for soil and 5.75 for hydroponics (Table 3).

The t-test was used to compare the data for calculating the Leaf Area Index (LAI) and find significant values at the

95% confidence level between the paired samples (soil and hydroponic system) for soil and hydroponics, two distinct independent growing systems [18] (Table 3). We started by examining Leven's test and the normalcy assumptions. Both hypotheses are true. There was little difference in the dirt scores. (M = 5.4, SD = 4.49) and hydroponics (M = 6.63, SD = 5.75); $t(12) = .443, p = .587$. As p value is greater than 0.05, so the null hypothesis is accepted.

Table 2 Assessment of leaf area index (LAI) after maturation for leafy vegetables cultivated in soil system

Name of plant	<i>A. viridis</i> L.	<i>T. foenum graecum</i> L.	<i>C. oleraceus</i> L.	<i>C. sativum</i> L.	<i>M. arvensis</i> L.	<i>C. arietinum</i> L.	<i>S. oleracea</i> L.
Average no. of plant in one quadrat (Mature and edible) + SD	27.22±2.94	80.78 ± 7.75	29 ± 4.44	92.56±6.54	17.78±5.44	25.89 ± 7.04	30.22 ± 6.68
Width of leaf w1+w2+w3/3 for one leaf	2.31 ± 0.22	1.19 ± 0.18	2.41 ± 0.28	1.81 ± 0.16	1.26 ± 0.22	0.62 ± 0.34	2.76 ± 0.24
Average no. of leaf per plant (10 plant taken)	21 ± 2.1	18 ± 3.22	16 ± 3.0	22 ± 4.6	13 ± 3.2	56 ± 6.2	12 ± 2.8
Width of one plant x No. of leaf	48.51	21.42	38.61	39.96	16.42	34.72	33.2
Length of Leaf	3.31 ± 0.60	2.14 ± 0.56	3.48 ± 0.65	3.09 ± 0.30	1.69 ± 0.51	1.11 ± 0.19	4.71 ± 1.06
Factor = Leaf area in graph / rectangle area in graph	0.6	0.5	0.8	0.73	0.75	1	0.77
Leaf area (cm square)	4.58	1.27	6.71	4.11	1.60	0.68	10.05
No. of plant in 1 square foot area	27.22	80.78	29	92.56	17.78	25.89	30.22
Total leaf area (cm square)	123.86	101.86	194.84	378.72	27.22	17.20	301.57
Land area per plant 30.48 (cm ²)	30.48	30.48	30.48	30.48	30.48	30.48	30.48
Leaf area index (cm ²) in square feet area	4.09	3.37	6.39	12.49	0.93	0.58	9.96

*cm² = centimeter square; One Square feet = 1 ft²

The evaluation of leafy vegetables grown in soil-based cultivation showed significant variation in leaf area index (LAI) among species. *Coriandrum sativum* (coriander) and *Spinacia oleracea* (spinach) recorded the highest leaf area index (LAI) values (12.49 and 9.96, respectively), indicating superior canopy development and photosynthetic efficiency in soil conditions. *Corchorus oleraceus* (6.39) and *Amaranthus viridis* (4.09) exhibited moderate leaf area index (LAI) values,

reflecting balanced growth and canopy coverage. In contrast, *Mentha arvensis* (0.93) and *Cicer arietinum* (0.58) displayed the lowest leaf area index (LAI), suggesting limited adaptability and productivity in soil cultivation. Overall, coriander and spinach emerged as the most promising leafy vegetables for maximizing yield potential under soil systems, while chickpea greens and mint were least suitable due to their restricted leaf area expansion [19-20].

Table 3 Assessment of leaf area index (LAI) after maturation for leafy vegetables cultivated in hydroponic system

Name of plant	<i>A. viridis</i> L.	<i>T. foenum graecum</i> L.	<i>C. oleraceus</i> L.	<i>C. sativum</i> L.	<i>M. arvensis</i> L.	<i>C. arietinum</i> L.	<i>S. oleracea</i> L.
Average no. of plant in one quadrat (Mature and edible) + SD	24.44±8.17	91.78 ± 13.58	23.67 ± 6.98	87.44±9.01	17.78±7.88	30.33 ± 8	32.11±8.46
Width of leaf w1+w2+w3/3 for one leaf	2.53 ± 0.14	1.26 ± 0.12	2.77 ± 0.38	2.25 ± 0.16	1.31 ± 0.28	0.58 ± 0.22	2.9 ± 0.17
Average no. of leaf per plant (10 plant taken)	23 ± 3.4	16 ± 4.0	15 ± 3.6	19 ± 4.8	19 ± 2.8	74 ± 7.2	8 ± 1.6
Width of one plant x No. of leaf	58.19	20.16	41.55	42.75	24.89	42.92	23.2
Length of Leaf	3.18 ± 0.46	2.14 ± 0.22	3.48 ± 0.66	3.09 ± 0.38	1.69 ± 0.18	1.11 ± 0.26	4.71±0.76
Factor = Leaf area in graph / rectangle area in graph	0.689	0.587	0.766	0.8	0.793	1	0.891
Leaf area (cm square)	5.5432806	1.5827868	7.3839336	5.562	1.7556227	0.6438	12.170169
No. of plant in 1 square foot area	24.44	91.78	23.67	87.44	17.78	30.33	32.11
Total leaf area (cm square)	133.0387344	175.6893348	169.8304728	483.894	29.8455859	19.314	389.445408
Land area per plant 30.48 (cm ²)	30.48	30.48	30.48	30.48	30.48	30.48	30.48
Leaf area index (cm ²) in square feet area*	4.44	4.76	5.73	15.95	1.02	0.64	12.82

*cm² = centimeter square; One Square feet = 1 ft²

The assessment of leaf area index (LAI) after maturation of leafy vegetables cultivated under hydroponic conditions revealed considerable variation among species. *Coriandrum sativum* (coriander) and *Spinacia oleracea* (spinach) exhibited the highest LAI values (15.95 and 12.82, respectively),

indicating superior canopy coverage and photosynthetic potential, making them highly efficient for hydroponic production systems. Moderate performance was observed in *Corchorus oleraceus* (5.73), *Trigonella foenum-graecum* (4.76), and *Amaranthus viridis* (4.44), reflecting a balanced

relationship between plant density and individual leaf size. In contrast, *Mentha arvensis* (1.02) and *Cicer arietinum* (0.64) showed the lowest LAI values due to their smaller or narrower leaves, despite higher leaf counts in chickpea greens. Overall, the study highlights coriander and spinach as the most suitable leafy vegetables for maximizing productivity in hydroponic systems, whereas chickpea and mint appear less favorable under the tested conditions [21].

CONCLUSION

Here we can conclude that an important characteristic of hydroponic systems was observed during the study through the calculation of LAI. Two leafy vegetable species, *S. oleracea* L. (12.82) and *C. sativum* L. (15.95), had high LAI values (Table 3). They have a lower total average number of leaves per mature plant, but they showed a higher economic growth rate (harvesting index) with an increased LAI value. Instead of increasing the number of leaves per plant, plants demonstrated their response by increasing the surface area of their leaves. Another observation was noted here. *C. oleraceus* L. (5.73) showed a lower LAI value in a hydroponic system as compared

to soil (6.39), but this was due to the lower average number of leaves per plant. There are so many other advantages of hydroponic systems that the leaf area index can be altered by manipulating environmental conditions and nutritional compositions provided in this study. This is a matter of investigation. Hydroponic systems are advancing day by day. Hence, lots of advancements are expected by agricultural scientists for developing easy and cost-effective methodology for growing plants through hydroponic systems.

Acknowledgement

My profound appreciation goes out to Dr. Arti Parganiha, Head of SLS at PRSU in Raipur (C.G.), India. Her knowledge and perception greatly influenced the direction and caliber of this work. Additionally, I would like to thank our laboratory's research scholars, Mr. Girdhar, Ms. Durgesh N. Parihar, Ms. Shilpi, and Ms. Shivangi, for providing the tools and assistance needed to complete this study. We would especially like to thank Dr. Parvez A. Khan, Mr. Suresh Sonkar, Mr. Arun Kumar Jangade, Mr. Bhaiya Sonkar, and Mr. P.L. Verma, whose cooperation and technical support were invaluable to this research.

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