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Research Article

Growth Performance of Green Oak, Red Oak, and Green Cos in a Deep Flow Technique Hydroponic System

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ABSTRACT

This study examined the growth performance and economic returns of three types of salad vegetables grown in a closed greenhouse using a deep flow technique (DFT) hydroponic system and adjusted to an electrical conductivity (EC) of 1.2–1.8 mS/cm and a pH of 5.6–6.5. The solution contained two balanced stock solutions: Stock A (N, P, K, Mg, S, Mo, B, Zn, Cu, and Mn) and Stock B (Ca and Fe). The study was conducted in Non Mak Khaeng, Watthana Nakhon, Sa Kaeo, Thailand, from March to April, 2024, utilizing a completely randomized design (CRD) with salad vegetable types as the treatment factor. Three lettuce varieties were tested: Green Oak, Red Oak, and Green Cos, with five replications of 10 plants each. The results revealed that Green Cos exhibited the highest growth performance in terms of root length (30.97 ± 0.32 cm), canopy height (19.33 ± 0.25 cm), and weight per plant (162.40 ± 5.29 g), with statistically significant differences ($p<0.05$) compared with Green Oak and Red Oak. However, Green Oak was recorded for the highest number of leaves (22.00 ± 1.00 leaves per plant). Survival rates were consistent at 100% across all three types. From an economic perspective, Green Cos yielded the highest profit of 4,872.54 THB, followed by Green Oak and Red Oak with profits of 4,526.94 THB and 3,867.88 THB, respectively. This research can be applied to the planning of salad vegetable production in a DFT hydroponic system to align with market goals. For example, it can help increase yields to meet the demands of health-conscious consumers, enhance competitiveness in the market, and ensure stable long-term income. Additionally, this approach supports the development of sustainable agricultural practice.

1. Introduction

Lettuce (*Lactuca sativa* L.), a plant commonly known as lettuce, is one of the most renowned leafy greens in the world and is in high demand both for consumption and export. This is due to its diverse nutritional value and beneficial antioxidant properties that promote health. Popular varieties of lettuce include Green Oak, Red Oak, and Green Cos, which are widely appreciated for their unique flavors and vibrant colors (Jiangseubchatveera *et al.*, 2023; Shi *et al.*, 2022). Additionally, lettuce is predominantly consumed fresh, making meticulous care essential throughout the cultivation process. Proper attention ensures that consumers receive high-quality produce that is free from toxic residues and contamination by harmful chemicals or microorganisms. These factors are crucial to lettuce cultivation and are the foundation for ensuring consumer confidence in the safety and quality of the produce (Lita, 2020).

In modern agriculture, farmers face numerous challenges that impact both the quantity and quality of production. Common issues include water scarcity, limited arable land, unpredictable climate changes, and outbreaks of plant diseases and pests. These factors often drive farmers to extensively use chemicals

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in cultivation, resulting in chemical residues in soil and crops, environmental toxicity, and health risks for both farmers and consumers. Additionally, traditional soil-based cultivation is susceptible to contamination by microorganisms, particularly in plant parts that come into direct contact with the soil (Siringam *et al.*, 2015). These challenges make achieving sustainable and efficient agricultural production increasingly difficult. Therefore, lettuce producers must carefully plan their cultivation to maximize returns in terms of yield, quality, and consumer benefits. In recent years, hydroponic technology has been adopted by farmers for its ability to accurately calculate fertilizer and nutrient formulas, preventing toxic or heavy metal residues in crops. This method aligns with policies aimed at reducing chemical use in pest management, enabling the production of high-quality crops that better meet market demands (Ekoungoulou and Mikouendanandi, 2020).

One of the most popular hydroponic techniques is the Deep Flow Technique (DFT), which continuously circulates nutrient-enriched water through plant roots. This technique ensures a steady supply of nutrients and oxygen to the roots, reduces water usage, and enhances plant growth efficiency. Furthermore, the DFT hydroponic system allows for easy environmental adjustments, making it suitable for cultivating various crops. In hydroponic systems, nutrient solutions are regulated by two key parameters, including pH and electrical conductivity (EC). Maintaining a stable pH level is crucial for optimal nutrient absorption by the roots. Exposure to solutions with excessively low pH can damage plants, while EC levels measure the nutrient concentration in the solution, requiring regular monitoring to ensure adequate nutrient supply. Each crop has specific optimal ranges for pH and EC, which must be managed carefully for successful cultivation (Pramono *et al.*, 2020).

The evaluation focuses on key parameters such as the number of leaves, root length, plant weight, canopy height, survival rate, and economic returns from the sale of the produce. The findings of this research are expected to provide valuable insights for farmers and agricultural entrepreneurs seeking to adopt hydroponic systems for lettuce production. Moreover, integrating innovative techniques like hydroponics into agricultural practices is anticipated to improve efficiency and foster sustainable farming.

2. Materials and Methods

2.1 Experimental Design

The study on the growth, yield quality, and economic returns of three lettuce varieties was conducted at the researchers would like to express their gratitude to Agricultural Learning Center of General Prem Tinsulanonda Statesman Foundation, Non Mak Khaeng Subdistrict, Watthana Nakhon District, Sa Kaeo province, Thailand. The experiment was designed using a completely randomized design (CRD), with three lettuce varieties as treatments: Green Oak, Red Oak, and Green Cos. Each treatment was replicated five times, with 10 plants per replication. The study aimed to analyze the number of leaves, root length, canopy height, fresh plant weight, and survival rate of the lettuce varieties, as well as to compare the profits generated from cultivating the three lettuce varieties per production cycle in the experimental greenhouse.

2.2 Preparation of the Greenhouse for Lettuce Cultivation in a Deep Flow Technique (DFT) Hydroponic System

The greenhouse used in this experiment had dimensions of 6 x 12 x 3 meters (width x length x depth), providing an internal area of 72 square meters. The roof was covered with 150-micron plastic, and insect nets with a mesh size of 40 were installed to protect the crops. The cultivation was conducted using DFT hydroponic system in which plant roots are immersed in nutrient solution containers with a solution depth of approximately 0.15 – 0.20 meters.

For this study, the greenhouse housed aluminum planting channels capable of accommodating 288 lettuce plants. There were four planting channels, each measuring 0.45 x 11 x 0.25 meters (width x length x depth). Each channel contained 72 planting holes spaced 0.15 meters apart in a staggered arrangement.

The irrigation system operated as a recirculating system, where nutrient solution flowed through each channel and drained into a 500-liter mixing tank. The water level in the tank was controlled by a float valve, and a pump circulated the solution back to the planting channels. The pump's pressure distributed nutrients evenly and increased oxygen levels for the plant roots, as illustrated in Figure 1.

(a) (b) (c)

Figure 1 Characteristics of a vegetable cultivation greenhouse (a) greenhouse, (b) growing trough, and (c) tank for mixing fertilizers A and B.

2.3 Nutrient Management and Application

The plant nutrient solution consists of two stock solutions. Stock A contains N, P, K, Mg, S, Mo, B, Zn, Cu, and Mn, while Stock B contains Ca and Fe. These two stock solutions must be prepared separately. To prepare the stock solutions, dissolve 1 kilogram of fertilizer in 10 liters of clean water, stir until completely dissolved, then seal the container and store it in a shaded area. When ready to use, measure equal amounts of Stock A and Stock B. Add Stock A to the mixing tank first, stir thoroughly until the solution is well-mixed, then add Stock B and stir again.

The adjustment of Stock A and Stock B is a crucial step in managing the nutrient levels for lettuce in the hydroponic system. In this study, a 500-liter mixing tank was used to prepare the solution, and an electrical conductivity (EC) meter was employed to measure the total nutrients in the solution. The nutrient solution was adjusted to an EC range of 1.2–1.8 mS/cm, which is suitable for lettuce growth. Subsequently, the pH was adjusted to a range of 5.6-6.5 by gradually adding nitric acid. Nutrient adjustments were conducted daily at 6:00 AM and 6:00 PM to maintain consistent nutrient levels and ensure optimal growing conditions for the lettuce.

2.4 Lettuce Cultivation Method in a Hydroponic System

The seed germination process begins by soaking sponge growing media in clean water for 24 hours to ensure sufficient moisture. Seeds are then placed into the prepared sponge holes, pressing them lightly to a depth of approximately 0.5 centimeters to position them optimally for germination. The sponges are placed in seedling trays and covered with clear plastic to maintain appropriate humidity and temperature. The trays are kept in a shaded area, away from direct sunlight, which provides an ideal environment for lettuce germination. Moisture levels in the sponge media are regularly checked, and distilled water is added as needed to prevent dryness or over-saturation. On the fourth day, when seeds begin to germinate and develop cotyledons, the plastic cover is removed to allow the seedlings to receive adequate light and air circulation. Germinated seedlings are then transferred to a location with soft natural light to prevent elongation and encourage the development of roots and true leaves.

At 14 days old, the seedlings will have developed 2–3 true leaves and a fully established root system. The seedlings are carefully transplanted into the DFT hydroponic system to avoid damage to the roots and stems. After transplanting, the plants are consistently monitored and maintained. Daily inspections are conducted to observe growth and address any issues such as plant diseases or nutrient deficiencies. Any identified problems are resolved immediately. To prevent pest infestations, a diluted wood vinegar solution is sprayed once a week. At 42 days old, when the lettuce plants reach maturity and are ready for harvest, fertilizer application is stopped 5 days before harvesting to minimize chemical residues in the produce. Observations of lettuce growth are conducted at key stages of development, specifically at 7, 14, 28, and 42 days, as illustrated in Figure 2.

Figure 2 Vegetable cultivation (a) seedling nursery (7 days) (b) transferring seedlings to planting channels (14 days) (c) 28 days and (d) harvesting the produce (42 days)

2.5 Survival Rate and Economic Returns of Three Lettuce Varieties

The economic returns from the sale of three lettuce varieties per production cycle were calculated for a single greenhouse. Each greenhouse can accommodate 288 lettuce plants per cycle, with an average production cost of approximately 740 THB per cycle. The production cost includes materials such as seeds, AB fertilizer, sponges, and wood vinegar. The calculation excludes the costs of greenhouse construction, the hydroponic system, water, electricity, and labor. The lettuce is sold at a price of 120 THB per kilogram. The survival rate of the lettuce and the profit from sales are calculated as follows:

1. Number of surviving plants per cycle = (Survival rate (%) ×100)/288 plants
2. Revenue per greenhouse = Number of surviving plants per cycle × (Average plant weight (g)/1000 kg) × Selling price
3. Profit per greenhouse = Revenue per greenhouse - Production cost

2.6 Data Analysis

The recorded growth data, including the number of leaves, canopy height, root length, and fresh weight of lettuce, were analyzed for variance (Analysis of Variance; ANOVA). The mean values from the experiments were compared using Duncan's New Multiple Range Test (DMRT) at a 95% confidence level, performed with statistical software.

3. Results and Discussion

3.1 Comparison of Leaf Count, Root Length, Canopy Height, and Weight of Green Oak, Red Oak, and Green Cos Lettuce Grown in a Deep Flow Technique Hydroponic System

Each treatment was replicated 5 times with 10 plants per replicate to compare the leaf count, root length, canopy height, and weight of the lettuce varieties grown in a DFT hydroponic system. The findings are presented in Table 1.

The experiment measuring leaf count revealed that Green Oak had the highest average number of leaves at 22.00 ± 1.00 leaves per plant, which was significantly different ($p < 0.05$) from Red Oak and Green Cos, with average leaf counts of 15.33 ± 0.58 and 16.67 ± 1.15 leaves per plant, respectively. This suggests that Green Oak has a greater ability to produce leaves, potentially due to genetic and physiological factors that promote leaf growth. Leaves are critical for plants as they play a key role in photosynthesis, energy production, and nutrient provision for growth and development (Maren and Sergi, 2021). However, the experiment also showed that Green Cos exhibited the highest average canopy height at 19.33 ± 0.25 cm, which was significantly different ($p < 0.05$) compared to Green Oak and Red Oak, with average heights of 14.30 ± 0.26 cm and 13.53 ± 0.15 cm, respectively. This could be attributed to genetic factors and the superior vertical growth potential of Green Cos. A taller canopy height enhances light interception for photosynthesis, reduces evapotranspiration, and helps maintain temperature balance in the environment. Farmers often use canopy height and leaf density as key indicators for assessing plant growth, yield potential, and planning crop management strategies (Buelvas *et al.*, 2019).

In Deep Flow Technique (DFT) hydroponic systems, efficient plant spacing is essential to maximizing yield and maintaining plant health. One of the key morphological traits that should guide spacing decisions is canopy height, which refers to the vertical extension of the plant's foliage. The average root length of Green Cos was the highest, measuring 30.97 ± 0.32 cm, which was significantly different ($p < 0.05$) from Green Oak and Red Oak, with root lengths of 27.10 ± 0.79 cm and 24.30 ± 0.97 cm, respectively. In DFT, plant roots are suspended in a continuously flowing nutrient solution, making root length and health critical for nutrient uptake. The extended root length of Green Cos increases the root surface area, allowing for greater contact with the nutrient solution. This enhances the plant's ability to absorb water and essential nutrients more efficiently. Plant roots play a critical role in water and nutrient absorption, which are essential factors for growth and yield. Longer and well-developed roots provide a larger surface area for nutrient uptake and enable plants to access nutrients in the solution more effectively compared to shorter roots. Therefore, the longer roots of Green Cos indicate a higher nutrient absorption potential, resulting in healthier growth and the highest weight per plant among the lettuce varieties studied in this research (Cochavi *et al.*, 2020). The average weight per plant also showed that Green Cos had the highest weight at 162.40 ± 5.29 grams, which was significantly different ($p < 0.05$) from Green Oak and Red Oak, with weights of 152.40 ± 5.29 grams and 133.33 ± 16.65 grams per plant, respectively. A higher weight per plant indicates greater yield, making Green Cos the most suitable choice for hydroponic production aimed at commercial sales.

3.2 Survival Rate and Profit Comparison of Three Lettuce Varieties

A comparison of the survival rate, total revenue, and profit of three lettuce varieties including Green Oak, Red Oak, and Green Cos grown in a DFT hydroponic system revealed that all three varieties had a survival rate of 100%. This indicates that the cultivation processes, fertilization, and environmental controls in this study were well-suited to support the growth of all three varieties.

Economic calculations in this study were based on one production cycle within a single greenhouse unit covering 72 m² and accommodating 288 lettuce plants. Green Cos generated the highest profit at 4,872.54 THB, followed by Green Oak with a profit of 4,526.94 THB, and Red Oak with the lowest profit at 3,867.88 THB (Table 2). These results highlight that Green Cos is the most commercially valuable lettuce variety, particularly for cultivation that prioritizes high yields and profitability. Green Oak, while slightly less profitable, is well-suited for markets that value lettuce with dense leaf production. In contrast, Red Oak, although yielding lower profits, stands out for its vibrant and appealing coloration, making it attractive for premium and decorative markets. Green Cos exhibited unique characteristics, including vertical growth, dark green leaves, and tightly layered foliage, with the tallest canopy height among the three varieties (Figure 3). These features make Green Cos an optimal choice for hydroponic production focused on maximizing both yield and economic returns.

Table 1 Comparison of leaf count, root length, canopy height and weight of Green Oak, Red Oak, and Green Cos lettuce grown in a deep flow technique hydroponic system

Cultivars	Number of leaves per plant	Root Length (cm)	Canopy Height (cm)	Weight /Plant (g)
Green Oak	22.00 ± 1.00^{a}	27.10 ± 0.79 ^{b}	14.30 ± 0.26^{b}	152.40 ± 5.29 ^{b}
Red Oak	15.33 ± 0.58^{b}	24.30 ± 0.97 ^{c}	13.53 ± 0.15^{c}	133.33 ± 16.65^{c}
Green Cos	16.67 ± 1.15^{b}	30.97 ± 0.32^{a}	19.33 ± 0.25^{a}	162.40 ± 5.29^{a}

^{a,b,c} Statistically significant differences at the 95% ($p < 0.05$) were determined using Duncan' new multiple rang test (DMRT)

Table 2 Survival rate of lettuce and comparison of profitability for growing three types of lettuce per production cycle

Cultivars	% Survival	Survival/ Greenhouse (plant)	Weight (g)	Income (Bath)	Profit (Bath)
Green Oak	100	288	152.40	5266.94	4,526.94
Red Oak	100	288	133.33	4,607.88	3,867.88
Green Cos	100	288	162.40	5612.54	4,872.54

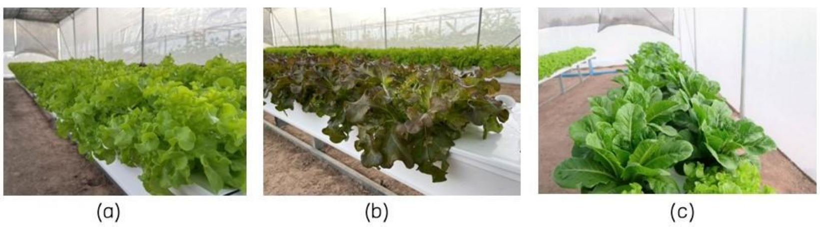

Figure 3 Characteristics of (a) Green Oak (b) Red Oak and (c) Green Cos grown in a deep flow technique hydroponic system

4. Conclusion

The experiment comparing the growth of Green Oak, Red Oak, and Green Cos lettuce in a DFT hydroponic system found that Green Cos exhibited the most outstanding performance in terms of root length (30.97 ± 0.32 cm), canopy height (19.33 ± 0.25 cm), and weight per plant (162.40 ± 5.29 g). This reflects its superior nutrient absorption efficiency and growth potential, making it highly suitable for commercial production. However, Green Oak had the highest number of leaves (22.00 ± 1.00 leaves per plant), making it ideal for markets demanding products with dense leaf structures. Although Red Oak yielded less than the other two varieties, it stood out for its vibrant coloration and visual appeal, making it well-suited for niche markets that prioritize attractive appearance. In terms of profitability, Green Cos generated the highest profit at 4,872.54 THB, followed by Green Oak at 4,526.94 THB, and Red Oak at 3,867.88 THB. These results indicate that Green Cos is the most suitable lettuce variety for commercial production, particularly for achieving high yields and profits. This research provides valuable insights for planning lettuce production in hydroponic systems to align with market goals, such as increasing yields for general markets, developing premium-grade products, or catering to health-conscious consumers.

For farmers, the findings highlight the advantages and limitations of each lettuce variety, enabling efficient crop planning. This includes selecting suitable lettuce varieties based on available resources and production goals, reducing costs by optimizing cultivation processes tailored to each plant's characteristics, and managing yields to meet market demand. Moreover, the research supports the adoption of hydroponic systems for sustainable agriculture by reducing water and chemical usage, minimizing pest risks, and adding value to products for export or premium markets. It also serves as a guide for advancing the agricultural profession in an era where consumers emphasize food quality and safety.

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