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Effect of Fluid Mechanics System in Growth of Vegetable Crops using Hydroponics Technique Compared to Conventional System

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ABSTRACT

Hydroponic techniques have major advancements in the recent years compared to Conventional Systems. The flow pattern of fluid used in hydroponic system in a cultivation container affects the growth of plants. Vegetables such as Strawberry, Basil, Cauliflower, Tomato, Spinach and Radish saplings were grown in soil and soilless methods to compare the growth, yield and nutritional value. As for the conventional system, the plants were grown in soil and for hydroponic system Nutrient Film Technique, Deep Water Culture and Wick Systems were used to cultivate plants. On the completion of the growth of the plants, the samples were analysed in laboratory for biochemical analyses. The total yield of Strawberry was 46.5% and tomato with 42.05% in Hydroponics system compared to soil system, whereas in Biochemical analysis Cauliflower gave 10.02% higher results. Chlorophyll content in Basil was observed to be 0.15mg/g and Spinach with 0.04 mg/g which was different from other corresponding results. The commercially harvested root of radish showed a total growth of 22.4 cm in the hydroponic system. The root and shoot lengths had significantly better results in Hydroponic system. Nutritionally, there were not many differences in few aspects whereas the hydroponically grown plants had better qualitative results. It was evident by the obtained results that, the hydroponically grown plants had better results when compared to the plants that were grown conventionally and the fluid flow patterns could also affect the productivity in the hydroponics system.

1. Introduction

In recent times, climate change is a global phenomenon which is a great concern for food security of the increasing population which is expected to be about 10 billion at the end of 2050 [1]. With the fast-growing global population, the demand for soil and land for crop production is likely to increase, and more urban area development need to be addressed by developing new and modified agricultural systems [2]. Natural resource management is a concern, as millions of hectares become unused because of soil degradation and other obstacles that is water, climate and energy, which will

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cause a problem for food production. Over the past 50 years, pesticides usage has raised by 42 times over the current usage among 2.5 million tonnes/year. In conventional method maintaining a constant soil moisture content at the soil surface will not be possible in all seasons. Chances of evaporation, soil texture, over irrigation in crop field, vapor flux and heat flux issues can occur [3]. Growing plants by using hydroponic method is one of those system to overcome these limitations [4]. Woodward in England (1699) tried to determine whether water or the solid portion of the soil was responsible for the plant growth [5]. Plants could be grown by flooding their roots in the Nutrient solution. The effect of flow rate of fluid required for cultivation of crops has gained increasing attention in recent years. The nutrient solution is either prepared from micronutrients or macronutrients [6]. The absorption of the nutrient concentration is higher in hydroponics when compared to traditional system. The distinction in every strategy depends on the structural set up, of Hydroponics [7]. Electric pumps will be used to supply nutrients solution to the plant root and a gravity system to drain of excess solution which can be recycled and reused. Ionic concentration and flow rates of the fluid used will be checked regularly. Optimum flow rates for hydroponics allow the plant to absorb nutrients for the growth in more efficient and productive way [8]. The prime focus in the study was to not only compare, but also to further experiment on alternative methods to grow plants in soilless systems, check the development rates, evaluate the sustainability of the plants, and also analyse the quality and quantity of the resultant yield.

2. Materials and Methods

2.1 Collection of Plant Samples

Seeds for the growth of the plants *Ocimum basilicum* L. (Basil), *Brassica oleracea* Pliny (Cauliflower), *Spinacia oleracea* L. (Spinach), *Raphanus sativus* L. (Radish), *Fragaria ananassa* Duchese (Strawberry), *Solanum lycopersicum* L. (Tomato) were procured from Suma Agro Hi-Tech Nursery, Mysore. Seeds samples were sown in a shallow plastic tray with drainage holes using coir dust as the growing medium. The trays were regularly watered. Between 7 and 10 days after germination, seedlings were pricked or transplanted individually to hydroponic and conventional systems.

2.2 Preparation of Nutrient Solution

Nutrient solutions are the mixture of micro and macro nutrients for the growth of the plants. Three sets of Nutrient solutions were prepared: Nutrient solution (A) consists of Iron Chelate; Nutrient solution (B) which consists of Magnesium sulphate, Potassium, Copper sulphide, Zinc sulphide and Manganese sulphide; Nutrient solution (C) which consists of Nitrogen, Potassium and Phosphorus. Each salt was dissolved in 1Kg/L capacity which acts as crude solution from which 1 ml each were extracted and mixed to form a combined nutrient solution. The pH of water taken for the experiment were 5.5 to 7, which was measured using a pH meter. The TDS were measured using a TDS meter.

2.3 Hydroponics

To grow the plants in hydroponics three types of systems were used.

i. Wick System
It is the simplest method of Hydroponics which does not require electricity, pump and aerators. After about 7 to 10 days of germination, 20 saplings from each vegetable crop were transferred to the wick system. Plants were placed in an absorbent medium like cocoa coir, vermiculite, Perlite with a nylon wick running from plant roots into a reservoir of nutrient solution. Water or nutrients solution supplied to plants through capillary action. In this system TDS must be maintained at 1050-1400 ppm and pH at 6.0-7.0. Wick system works well for small plants, herbs and spices and does not work efficiently that needs lot of water.

ii. Nutrient film technique
In this system, water or a nutrient solution circulates throughout the entire system; and enters the growth tray via a water pump without a time control [9]. The nutrient film technique system is at forefront of people's mind when Hydroponics is mentioned. The solution will be pumped from reservoir into the growing tray. The roots draw the nutrients from the flowing solution. The downward flow of water moves back into the reservoir to get recycled. Pump and electric maintenance are essential to avoid system failure, where roots can dry out rapidly when the flow stops [10]. In this system 20 plants were chosen for hydroponic method and 20 plants were chosen for soil-based method. NFT system consists of growing tray, water reservoir and electricity to pump water. The growing trays were connected to the water reservoir through tubes. The water reservoir contains a water pump, from which a few small tubes rise which are connected to the growing trays. On supply of electricity, the water from there gets pumped to the trays. The water reservoir contains the nutrient solution. The saplings were placed in net pots with the root in contact with the flowing water. Gravels were placed in net pots for mechanical support. The pH must be maintained at 5.5-6.5 and TDS at 300-600 ppm.

iii. Deep water culture system
Hydroponics buckets system is classical example of deep-water culture system. Plants were placed in net pots and roots were suspended in nutrient solution where they grow quickly in a large mass. It is mandatory to monitor the oxygen and nutrient concentrations, pH and salinity to avoid growth of moulds and algae which can grow rapidly in the reservoir. This system works well for a large plant [11]. Plastic tubs with a lid were taken, the lids of the containers were made hole for the net pots to fit in. 20 saplings of each vegetable crop were placed in net pots and LECA were used for mechanical support. The pH must be maintained at 5.5-6.5 and TDS at 700-1120ppm.

2.4 Soil System

For the traditional soil planting**,** soil to be used was first grounded to have a fine texture, and this was done to enhance penetration and proper mixing of nutrients with the soil particles. 10 kg of livestock manure was mixed properly with the fine soil. The inorganic fertilisers like DAP (Di-ammonium Phosphate) and urea were added to the soil. 20 seedlings from each vegetable crops were transferred two weeks after the planted seeds had germinated. Sufficient water was provided 2 times a day as required.

2.5 Parameters for the Growth of Plant

Various measuring parameters were used for the calculation of plant growth. Average shoot length, average root length, enumeration of flowers and fruits, width of leaves, total yield of vegetables were calculated in triplicates. Conventional as well as hydroponic techniques were measured separately.

2.6 Biochemical Analysis

Harvested crop was used for estimation of protein, chlorophyll, carbohydrates, fats, minerals.

i. Estimation of Protein Analysis: The protein content was estimated by UV-Vis spectrophotometric technique using the conventional Lowry's method [12].
ii. Determination of fat content: The fat content present in vegetable crop was analyzed using Folch Method [13].
iii. Detection of carbohydrates: The Carbohydrate content the vegetables was estimated using Benedict's test [14].
iv. Test for Sodium and Potassium: Sodium and Potassium content in leafy vegetables were estimated by using standard procedure [15].
v. Total Energy: The total energy of one serving of the sample were calculated by adding together the energy provided by the protein, total fat, carbohydrate and dietary fiber.
vi. Total Chlorophyll content: Chlorophyll extracted from the leaves were characterized by UV-Visible spectroscopy [16].
vii. Detection of Heavy Metals: Heavy metals were detected by using Atomic Absorption Spectrophotometer [17].

3. Results and Discussions

The efficiency of the given hydroponic system and conventional system is based on the plant growth in the minimum possible days. The germination period of the subjected crops in hydroponics was earlier than in conventional method. Comparatively the plant survival rate of hydroponic plants was more than conventional method (Table 1). This was because, in hydroponics the water and nutrients supplied were directly made available to the roots due to which, the nutrients and water were absorbed in sufficient amount. The height of hydroponically cultivated crops was higher in strawberry, cauliflower and Basil with 14cm, 14.17cm and 14cm respectively than the conventionally cultivated crops (Figure 1). A greater yield was obtained in strawberry, cauliflower and basil. The mean yield of Hydroponic system had a significant difference, which depicted a contrast between the working of the two above mentioned systems. Similar results observed where an increment of 87% of total yield in hydroponics when compared to the conventional method [7]. Significant effect of different growing systems on root and shoot ratio and found maximum difference in root and shoot ratio from the plants grown in Hydroponic growing system [18]. Both pH and temperature play an important role in plant growth. The water pH in hydroponic (6.5± 0.5) and soil (8.6) systems had much significant difference. The neutral pH is well within the desirable range, as the optimum growth of plants occurs at pH 6-7. The mean daytime water temperature in the water reservoir and tanks was 23.4±0.41^{o} C and the greenhouse mean daytime air temperature was 27±0.6^{o} C. The EC of water was 862 S/m and the soil EC65 S/m. Several fluctuations in pH were recorded in conventional system throughout the growth period of plants and no such changes were seen in the pH of hydroponic systems as it was maintained constantly throughout the experiment.

Table 1
Plant Survival Rate and Yield of vegetable compared with Hydroponic and Conventional plants

Sl No	Crop	Growing technique	No of plants planted	No. of plants survived	Percentage	Total yield in gms	Percentage of yield
1	Strawberry	Hydroponic	20	14	70%	363	64.70%
		Conventional	20	9	45%	198	35.29%
2	Cauliflower	Hydroponic	20	16	80%	762	61.7%
		Conventional	20	11	55%	473	38.29%
3	Tomato	Hydroponic	20	17	85%	595	64.88%
		Conventional	20	12	60%	322	35.11%
4	Radish	Hydroponic	20	19	95%	657	55.81%
		Conventional	20	15	75%	520	44.18%
5	Spinach	Hydroponic	20	20	100%	110	55.83%
		Conventional	20	17	85%	87	44.16%
6	Basil	Hydroponic	20	20	100%	50	59.52%
		Conventional	20	19	95%	34	40.47%

In biochemical analysis total protein content was showed slight variations in Cauliflower as hydroponically grown showed 2.09% and conventionally grown cauliflower showed 1.84%, as the roots being in direct contact with the nutrient solution, uptake of nitrogen is favoured accounting for more protein content in hydroponically grown conditions (Figure 1 and Figure 2). Increase in the yield of vegetables was seen in soilless culture [19]. The total protein content was 3.49% more in the hydroponically grown radishes, than in soil grown radishes and individually, the hydroponic tomatoes had 4.3% and soil grown tomatoes had 0.81%. The percentage of carbohydrates and fats was found to be 5.25% and 0.23% respectively in hydroponically grown cauliflower and 4.96% and 0.21% respectively in conventionally grown cauliflower, as the rate of photosynthesis is more in hydroponically grown plants as the temperature was maintained constantly. There was a difference of 0.15% in the carbohydrates present between the radishes grown in both the systems, where the amount of carbohydrates in the hydroponically grown radishes was 5.14% and 4.99% in the soil-based radishes. Upon analysis, the fat percentage in the hydroponically grown was 0.12% and 0.1 % in soil system grown radishes. Higher the temperature, greater the rate of photosynthesis.

The Sodium and Potassium content was highest in hydroponically grown cauliflower with 8.07mg/100g and 298.52 mg/g respectively, as compared to conventionally grown cauliflower with 3.05 mg/100g was 262.71mg/g respectively, as Sodium and Potassium present in nutrient solution is in its cation form which is an extremely soluble ion. The sodium content in hydroponic grown radishes was found to be 47.99mg/100g whereas in soil grown radishes was 40.59mg/100g. Similarly, the amount of Potassium in the soil grown radishes was 178.73 mg/100g and 148.02mg/100g in the radishes grown in hydroponic system. There was a difference of 7.4% in the sodium concentration and 30.71% difference of Potassium (K) concentration, upon analysis of both the systems. Total Energy of cauliflower grown in hydroponic system was 31.43kcal/100g higher compared to conventional grown cauliflower with 28.38kcal/100g. The total energy in the hydroponically grown radishes was 25.04 kCal/100g and in the soil grown radishes, 24.1 kCal/100g. The difference between the two was found to be 0.94 kCal/100g, higher in hydroponic system.

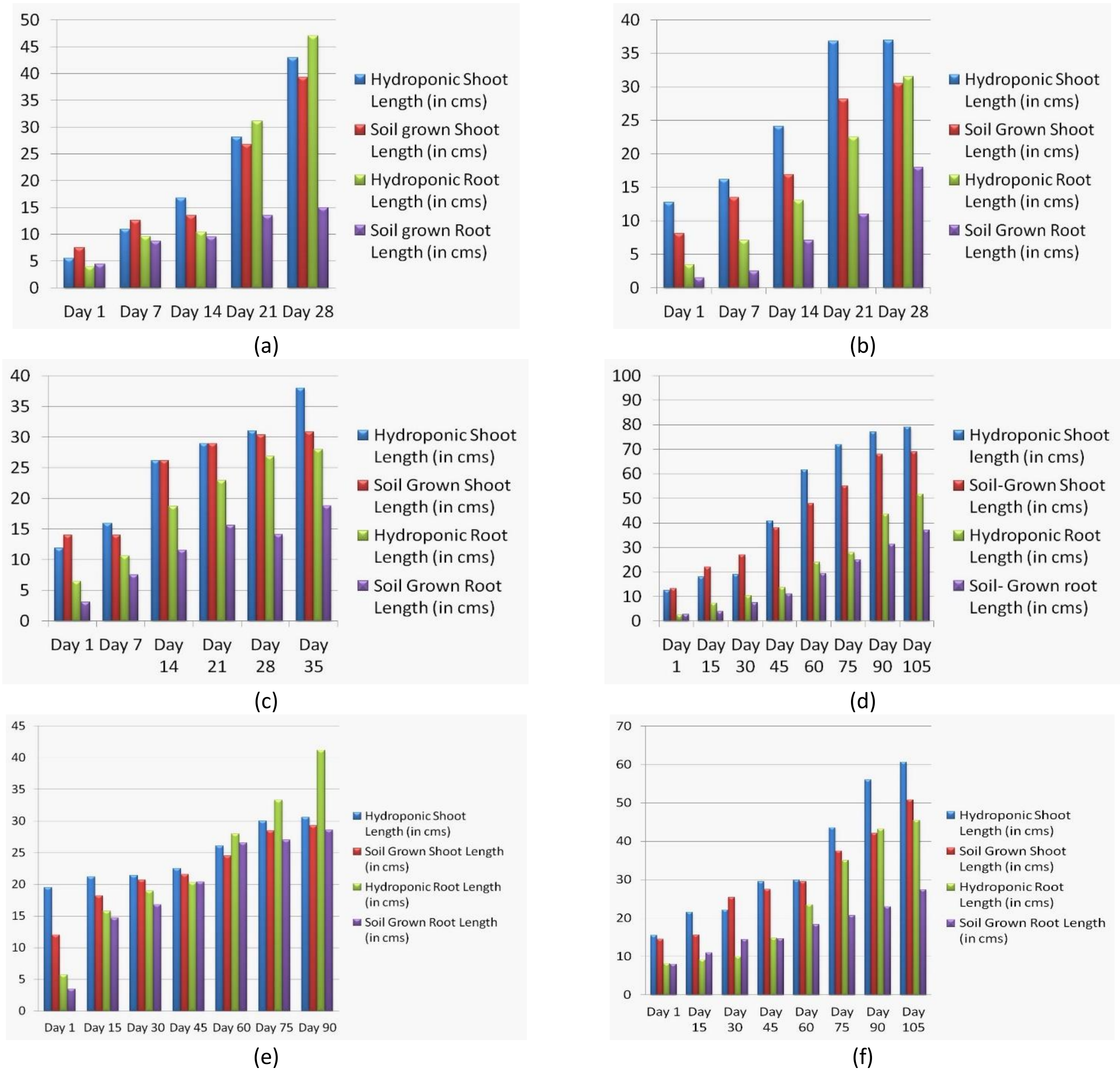
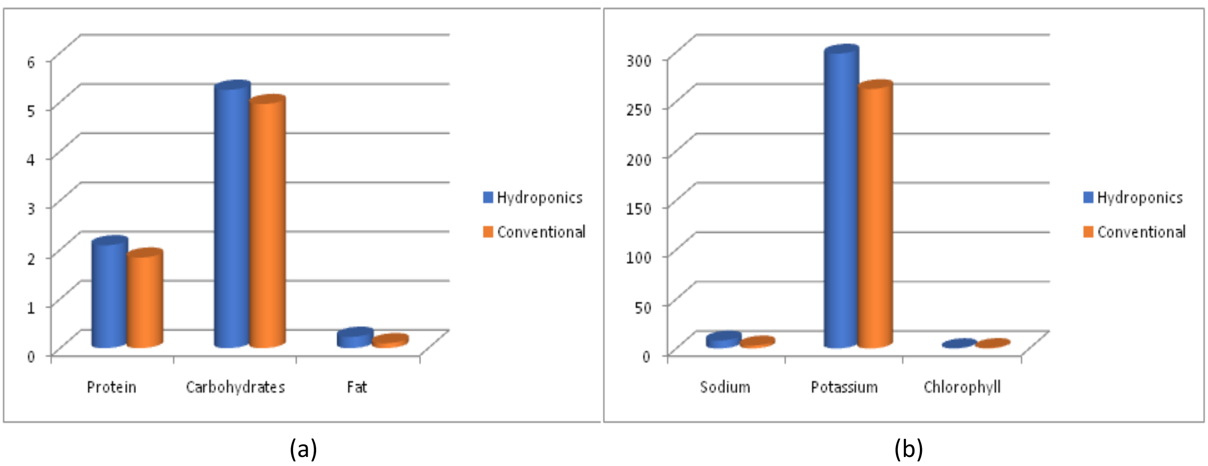


Fig. 1. Root length and Shoot length Data of Hydroponic v/s Conventional Method: (a) Strawberry (b) Tomato (c) Cauliflower (d) Spinach (e) Radish (f) Basil

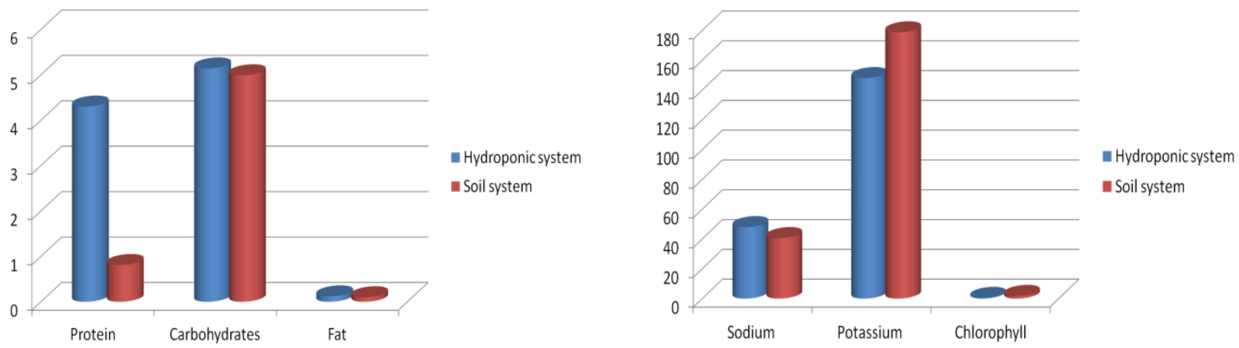


(a) (b)

Fig. 2. Biochemical analysis and comparative analysis (a) protein, carbohydrates, and fats of Tomato plant (b) Minerals and chlorophyll of Spinach

The heavy metal tested in soil and the nutrition supplemented water was Lead (Pb) (Figure 3). The analysis showed that the soil had 379 mg/kg and in the water of the hydroponic system the concentration was Below Detection Level (BDL). According to a study, hydroponically grown Basil indicated the presence of only Copper when subjected to a heavy metal test, which was within the permitted limits [20]. Chlorophyll content was 0.37 mg/g in hydroponically grown Basil and 0.52 mg/g in conventionally grown Basil. The possible reason for increase the chlorophyll content in conventional system could be because the plants were subjected to direct sunlight, and they received maximum amount of energy favoured according for more chlorophyll content in them. The total chlorophyll content of 0.47mg/g was procured from the hydroponically grown spinach and 0.51mg/g in spinach grown in soil system. A difference of 0.04 mg/g was higher in the soil-based system. Similar results were reported where the chlorophyll content was higher in the hydroponically grown pea plant with approximately 0.4200 mg/lt [21].

The findings of these studies demonstrate that the flow rate in hydroponic systems influences the growth of plants, and the flow rate can be regulated to improve crop yield. Ideal flow rates to promote the growth of hydroponic crops provide adequate contact time [22] and collision frequency between roots and nutrient ions to promote nutrient absorption, which subsequently enhances plant growth.



(a) (b)

Fig. 3. Biochemical analysis and comparative analysis (a) protein, carbohydrates and fats of Cauliflower plant (b) Minerals and chlorophyll of Basil

4. Conclusions

Hydroponics is the great way to grow plants in the places where a very limited space is available (urban areas) and soil is not fertile. Water used in hydroponics can be recycled and reused, and no water goes to waste as it is water efficient technique of cultivation. No chance of soil-borne diseases, weed infestation, insect or pest attack in hydroponics. It produces the healthiest and nutritious crop with high yield. Higher yield of hydroponics was from the controlled environmental conditions maintained within the hydroponic greenhouse, which allow for continuous production year-round. This opens scope for further studies in the emerging field of Hydroponics to focus on growing commercial crops on a large scale using soilless techniques. Methods that utilize less space and soilless cultures can help in overcoming the scarcity of fertile agricultural land. Emphasis can be made on the characteristics of the fluids and models used to cultivate, which can result in higher yields. Different varying parameters can be combined to increase the efficiency of growing crops.

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