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The Study of Turbulent Nutrient Solution Flows in Difference Hydroponics System Arrangements

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Abstract. This work studied the turbulent flow of the nutrient solution which affected the growth of plants in four hydroponic systems; the horizontal (traditional), the vertical cup-grown, the ladder and the droplet systems, which were connected with individual solution pumps which submerged in only one nutrient solution tank to supply the turbulent nutrient solution flow to all systems. Two experiments were done by planting Red Oak lettuce, fluid and ambient temperatures, fluid pH and sunlight intensity were measured 2 times a day from 4 systems placed in the same area and environment during 20 days of the experimental periods. From both result sets, the lower ambient and solution temperatures in the 2nd experiment yielded more productivity. The results also showed that adjusting pipe and hose sizes did not cause the nutrient solution overflow out of the systems, the turbulent flow occurred and the horizontal system could produce the highest productivity. However, the higher pump power was required to produce the turbulent solution, the higher pump power higher heat transfer from the pump to the nutrient solution in the tank since all pumps were placed in the same solution tank, this heated solution caused the lower productivity in this work.

Introduction

Hydroponics is a plant growth system that provides a more precise control of growth media composition. The ease of system set up, cost of the growth system and flexibility to characterize and harvest plant material were continually improved in new hydroponic system [1]. Hydroponics methodology for plant biological researches has several main focuses such as preparation of hydroponic nutrient solution, use of this technique for studying biological aspects and environmental controls, and production of vegetables and ornamentals hydroponically [2]. The production increases crop quality and productivity, which results in higher competitiveness and economic incomes and the nutrient solution is considered to be one of the most important determining factors of crop yield and quality [2]. Since hydroponics does not require natural precipitation or fertile land in order to be effective, it presents people who are living in arid regions with a means to grow food for themselves and for profit [3]. They also claimed that aeroponic and hydroponic systems do not require pesticides, require less water and space than traditional agricultural systems, and may be stacked in order to limit space use as in vertical farming [4,5]. This work supported them for use in cities, where space is particularly limited and populations are high-self-sustaining city-based food systems mean a reduced strain on distant farms, the reduction of habitat intrusions, fewer food miles, and fewer carbon emissions [3]. Trejo-Téllez and Gómez-Merino [2] presented that the nutrient solution for hydroponic systems is an aqueous solution containing mainly inorganics ions from soluble salts of essential elements for higher plants. Salisbury and Ross [6] reported that there were 17 elements which were considered essential for most plants. The pH value of the nutrient solution determines the nutrient availability for plants [7], the proper pH values of nutrient solution for the development of crops lies between 5.5 and 6.5 [2]. The solution in hydroponics systems can move in its various forms such as drip and flow style irrigation, limits the threat of water waste via over- or poorly-timed irrigation because water loss due to evaporation, and limits freshwater habitat abuses [3,8]. Genuncio et al. [9] studied hydroponic lettuce production to evaluate the accumulation of fresh weight of hydroponic lettuce in terms of ionic concentrations and flow rates of nutrient solution. Their work consisted of three experiments only in Nutrient Film Technique (NFT) hydroponic system which was the horizontal (traditional) setup but the nutrient flow was shallow like film, conducted between July and September 2006. They concluded that the application of nutrient solution at a flow rate of 1.5 L min^{-1}, as well as 100% of the ionic concentration was effective to increase the fresh weight of the aerial part of cultivars, Lucy Brown, Izabela and Veneza when grown in hydroponics.

Pramuanjaroenkij et al. [8] presented the fluid flow in the four hydroponics systems and created four hydroponics systems; horizontal (traditional), inclined-flow, vertical-droplet and vertical-bowl systems. Each prototype was connected with its individual nutrient solution tank and placed in the same area and environment during 15 days. The vertical-droplet system could not be used to grow Red Oak because the plants died during the experiment period. The vertical-bowl system could provide the highest productivity. We noticed that the fluid in the vertical-bowl system flowed transitionally while the flow in the other systems was laminar. Therefore, the fluid flow patterns could affect the productivity in the hydroponics systems.

Since there were some limitations on planting area and cost of commercial hydroponics systems, this work focused on developing and testing all four hydroponic prototypes [8] for household utilization with the turbulent nutrient solution flow in every system. Red Oak was used to plant in all prototypes to investigate the prototype productivity. All variables; fluid and ambient temperatures, fluid pH and sunlight intensity were measured two times a day from all four systems placed in the same area and environment during 20 days of the experimental period. Additionally, there was only one nutrient solution tank to supply the solution to all four systems, which was different from our previous work [8].

Experimental Procedure

Experimental procedures consisted of (1) All four hydroponic prototypes were prepared for the turbulent nutrient solution flow, we paid attentions to the nutrient solution overflow out of the systems, (2) Selecting solution pumps, (3) Placing all 4 prototypes in the same greenhouse and all pumps were submerged in the same solution tank to supply the turbulent solution flow, (4) Placing five Red Oak saplings on four developed prototypes, (5) Measuring parameters, (6) Measuring final products from four prototypes after 20 days and (7) Repeating Steps 3 to 6 for the 2^{nd} experiment.

Results and Discussion

The developed hydroponic prototypes for household applications are shown in Figures 1 (c) to 4 (c). After the prototypes were adjusted and developed, the solution pumps for all four hydroponics systems were selected at the same size at 60 Watts, the pumping power were calculated to confirm that the nutrient solution flow was turbulent; the chosen watts of the pumps were also based on watts of pumps which were available in the local markets. After the developed prototypes were connected to one nutrient solution tank to supply the turbulent nutrient solution flow to all systems, Red Oak saplings were planted in each prototype. The vertical-droplet hydroponics system which could not be used to grow Red Oak in our previous work [8] was adjusted by inserting a 1-inch diameter PVC tube inside the first prototype; a 3-inch diameter PVC tube, to control the solution, so the solution did not touch the leaves of the plants and the plant roots could fully absorb the nutrient. Red Oak plants from all four systems were measured for their weights, root lengths and plant lengths to investigate the prototype production, the parameters were expressed in Tables 1. We chose the same solution pumps for all developed prototype but we put all four pump into one nutrient solution tank to supply the turbulent nutrient solution flow to all systems. The nutrient solution flow velocity was calculated and found to be turbulent, so all prototypes were fed with the same flow profiles. The turbulent solution also implied that the solution could be mixed during the flow better than in that of the laminar flow but higher pump power higher heat transfer from the pump to the nutrient solution in the tank since all pumps were placed in the same solution tank, this heated solution caused the lower productivity in this work. From Tables 1 and 3 during the day in both months; October and November, the average solution temperatures among 5 holes obtained from the vertical-bowl system were the highest temperatures, this might be caused by some solution left in the bowls (the collected solution in the bowls). From Tables 1 and 3 during the night in both months; October and November, the average solution temperatures among 5 holes obtained from the horizontal system were the highest temperatures, it exposed to sunlight the most and others had some shading on the lower holes causing lower solution temperatures in the lower holes. The average solution temperature results from the current work agreed well with the literature [8]. From Tables 2 and 4, the horizontal system could provide the heaviest products and the second longest total length, the turbulent flow in the the horizontal system could enhance the lettuce productivity, the faster the nutrient flow the greater fresh mass of the lettuce as in the literature [9]. We noted that the nutrient solution flow was laminar flow in the horizontal system from the literature [8] which was different from the current work. The results from Tables 2 and 4 indicated that our developed vertical-droplet hydroponics system could be used to grow Red Oak since the new arrangement could provide the solution for the plant roots and the solution did not touch the leaves of the plants. We also marked that the total productivity measured from the current work was lower than that measured from our previous work [8], this may be caused by the different ambient temperature, the global warming around the world played an important role in Thailand, the ambient temperatures in October and November in 2014 were a lot higher than in previous years. We would like to emphasized that, to utilize the hydroponics systems, one must learn how to cultivate saplings and if the roots of the plants are not long enough, the plants will grow poorly or slowly, the temperature and velocity of the nutrient solution play important roles on the growth as well.

(a) (b) (c) (d)

Fig. 1 The developed hydroponics systems; (a) the horizontal, (b) the ladder, (c) the vertical cup-grown and (d) the droplet.

Table 1 Red Oak products and nutrient temperatures.

Systems	Total Red Oak Products 1st result/ 2nd result	Average temperatures in Celsius among 5 holes 1st result/2nd result in Celsius		Different temperatures in Celsius between a reservoir and holes 1st result/2nd result	
		Day	**Night**	**Day**	**Night**
Horizontal system	52 g 100 cm/ 116 g 116 cm	33.53/31.25	30.27/28.74	–0.253/–0.638 (higher T_{reser})	–0.003/–0.117 (higher T_{reser})
Inclined-flow system	37 g 76.1 cm/ 58 g 68 cm	32.00/31.37	30.19/28.54	–0.223/–0.512 (higher T_{reser})	0.146/–0.320 (higher T_{hole})/ (higher T_{reser})
Vertical-droplet system	33 g 108 cm/ 54 g 47 cm	33.53/31.46	29.84/28.57	–0.088/–0.422 (higher T_{reser})	–0.542/–0.290 (higher T_{reser})
Vertical-bowl system	35 g 66 cm/ 22 g 55.5 cm	33.59/31.68	30.12/28.59	–0.154/–0.205 (higher T_{reser})	–0.106/–0.275 (higher T_{reser})

Summary

During 20 days of the experimental period in October and November 2014, the temperatures affected the productivity. The hydroponics system with the vertical-droplet flow could be used in planting Red Oak after the vertical-droplet system was developed. Among the four developed hydroponics systems, all systems were connected with the same pump power size, the horizontal (traditional) system could provide the highest productivity. However, the higher pump power was required to produce the turbulent solution, the higher pump power higher heat transfer from the pump to the nutrient solution in the tank since all pumps were placed in the same solution tank, this heated solution caused the lower productivity in this work. Since the hydroponics systems suit for limited and populations are high-self-sustaining city-based food systems, the horizontal (traditional) system was recommended for places with available areas while the vertical-bowl system suits for small areas.

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