The recirculated hydroponic system for strawberry nursery production in plant factories

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1. Abstract

Plant factories could be used as a bioreactor for the production of disease free and PGR free (plant growth regulator) daughter plants in strawberry. The recirculated hydroponic system often resulted in growth retarded and physiological disorder in strawberry. The improved recirculated system provided the environment with stable EC and pH value, which enable strawberry plants to grow much vigorous and produce more runners. The concentration of NO_3^-, K^+, Ca^{2+}, Mg^+, and SO_4^{2-} in the solution was measured, and the ion content and consumption in the solution was calculated. A new solution was designed for reducing the frequency of solution renewing and release the plants from suffering the accumulation of certain ion according to the solution analysis. For reducing the labor cost, the cultivation support for easy rooting is also testing.

Keywords: solution ion content, solution ion consumption, cultivation support

2. INTRODUCTION

Plant factory with artificial light (PFAL), an airtight warehouse-like structure with the characters of thermally insulated, humidity stable and pathogen-free (Kozai, 2013), benefits plant growth in undesirable season or environment. In addition, land use efficiency may promote several folds by multiple culture shelves design. Therefore, the application of PFAL in planting shorter plants (<30 cm) is favorable particularly in the country with high population density. Hydroponic culture is one of the soilless culture usually applied inside the facilities.

Closed hydroponic is a growing system that the nutrient solution is recycled instead of released into the environment (Ruijs, 1992). According to the depth of nutrient solution, there are deep-flow technique (DFT) and nutrient film technique (NFT) systems (Jensen, 1999). In closed system, growth of strawberry is often stunted in regardless by DFT or NFT systems due to the accumulation of root exudates and spread of soil-borne pathogens (Kitazawa *et al*., 2005; Martíneza et al., 2010). Methods to alleviate the deleterious effects developed such as adding activated charcoal, electrodegradation or applying sand filters (Asao et al., 2008; Kitazawa et al., 2005; Martíneza et al., 2010). In our previous study, we grew strawberry in PFAL-DFT system, and the plants stopped growing right after moving

into the system and severe physiological disorder was gradually appeared within the following 2 weeks. The phenomenon revealed that factors aside from the accumulation of toxic root exudates may strongly interfere plant growth (Hung, 2013). We hypothesized that recirculation driven pump might be the cause. Therefore, the objective of this study was first to replace the submersible motor with non-submersible types to evaluate the possibility of planting strawberry in Enshi solution with closed hydroponic system in PFAL. We also emphasized on enhancing daughter plant production and estimating the turn-over rate of the mother plant in the production system.

3. MATERIALS AND METHODS

Plant material

'Taoyuan No.1' was the selected cultivar in this study. The mother plants were cultivated from daughter plants for 8-9 weeks in hydroponic system in NTU plant factory A3 room with temperature setting at 20 ^{o}C and lighting period for 16 hr. The cultivating shelves composed 3-4 cultivating bed vertically, each cultivating bed was 110 cm x 50 cm in size and equipped with 9 Philips TL5 fluorescent lamps (28W/865 6500K) 25 cm above. The light intensity was 360-160μmol m^{-2} s^{-1} measured form 5 cm below the lamps to the cultivating plane. Data logger (UA-002-64, Onset Hobo, MA, USA) were placed on the central of cultivating bed, and the actual temperature recorded was 24 /19^{o}C (light /dark). The leaves of mother plants were trimmed every week and maintain to have 2-3 leaves to avoid shading. The new leaf generation, leaf area after old leaf removal, crown diameter, SPAD value (SPAD-502, Spectrum Technologies, Plainfield, IL, USA) and runner formation was recorded weekly in Experiment I (Exp I). The new leaf was characterized as they unfolded. In experiment II, runner and daughter plant formation was recorded at harvest when the daughter plants cover the cultural plane.

Hydroponic system

Experiment I (Exp I) was testing recirculation system against non-circulation system. The recirculation systems were driven by booster and magnetic drive pumps, and which were tested against the non-circulation system (CK). The culture solution in Exp I was Enshi (E) (Kitazawa et al., 2005), and modified Enshi (ME) was formulated according to the nutrient consumption of Exp I in experiment II (Exp II). In recirculation system, the solution of Exp I was adjusted every 8 days by suppling nutrient solution. In Exp II, the solution was adjusted weekly either by suppling nutrient solution (EC $\leq$ 0.75 ds/m) or water to the tank. The pH was titrated to 6.5 after the supplement.The hydroponic solution was sampled before and after the adjustment for HPLC (IA-300, DKK-TOA Corporation, Japan, Cationic column: PCI-205l, Anion column:PCI-322) analysis in Exp I. The solution in non-circulation system was renewed in the interval of 8 days. The duration of Exp I was 48 days; the recirculation solution was renewed every 8 weeks in Exp II.

Data Analysis

The experiment was arranged in a completely random design. All data were analyzed by Fisher least significant difference (LSD) test ($P< 0.05$) and subjected to analysis of variance (ANOVA). Graphing was performed with Sigma Plot 10.0 (Systat Software, Inc., San Jose, CA, USA)

4. RESULTS

Magnetic drive pump-recirculation system can grow strawberry hydroponically

The appearance of the plants was indistinguishable among the plants that grown in recirculation and non-circulation system within the 8 weeks of experimental period (Fig 1). The shoot biomass, both fresh and dry weight, were significant higher in recirculation than non-circulation system in regardless of booster and magnetic drive pump (Table 1); however, the root growth showed no difference among the 3 systems. The pH value maintained rather constant, ranging 6.2-7.0, throughout the experimental period in the recirculation systems (Fig 2). In non-circulation system, the pH value dropped to 5.5 within the first 2 days right after the renewing of the solution and climbing back to 6.5 gradually in the following days. For the EC value, magnetic drive-pump recirculation system and non-circulation system maintained closed to the setting 0.6, while the booster pump-recirculation system kept climbing and up to 0.84 (Fig 3).

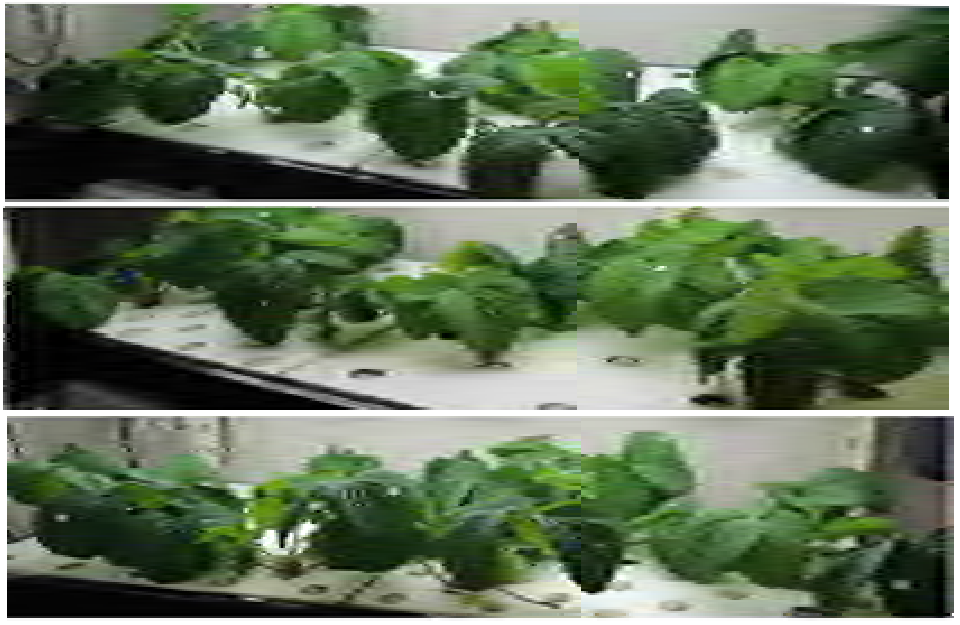

Fig 1. The growth of ‘Taoyuan No.1’ grown under (A) non-circulation system, (B) booster pump and (C) magnetic drive pump-recirculation systems. The photo was taken at 41st days after transferred into the systems. The hydroponic solution of the non-circulation system was refreshed in every 8 days. The experiment was conducted from 23 Jul. to 9 Sep. 2014.

Table 1. The biomass of 'Taoyuan No.1' strawberry at the end of the comparable experiment among non-circulation system, booster pump and magnetic drive pump-recirculation systems. The experimental duration was 48 days.

System[z]	Shoot			Root			S/R DW ratio
	FW (g)	DW (g)	Dry matter (%)	FW (g)	DW (g)	Dry matter (%)	
Non-circulation	34.67 a	13.22 a	38.12 a	30.64 a	3.76 a	12.29 a	8.14a
Booster pump	38.25 a	14.03 a	36.68 a	31.93 a	3.64 a	11.41 a	8.76a
Magnetic pump	41.00 a	14.30 a	34.87 a	36.99 a	4.05 a	10.94 a	9.14a
$LSD_{0.05}$[y]	NS	NS	NS	NS	NS	NS	NS
Non-circulation	34.67 b	13.22 b	38.12 a	30.64 a	3.76 a	12.29 a	8.14a
Booster pump	38.25 a	14.03 a	36.68 a	31.93 a	3.64 a	11.41 a	8.76a
$LSD_{0.05}$	*	*	NS	NS	NS	NS	NS
Non-circulation	34.67 b	13.22 b	38.12 a	30.64 b	3.76 a	12.29 a	8.14a
Magnetic pump	41.00 a	14.30 a	34.87 b	36.99 a	4.05 a	10.94 b	9.14a
$LSD_{0.05}$	**	*	**	*	NS	**	NS
Booster pump	38.25 a	14.03 a	36.68 a	31.93 a	3.64 a	11.41 a	8.76a
Magnetic pump	41.00 a	14.30 a	34.87 a	36.99 a	4.05 a	10.94 a	9.14a
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS

[z]Two recirculation system was with 2 replicates, and each replicate was with 12 plant. The non-circulation system was with 12 plants.
[y]Statistical analyses were conducted using ANOVA (Costat 6.2, CoHort Software, USA) and the means compared with LSD test with a significance level $p< 0.05$.

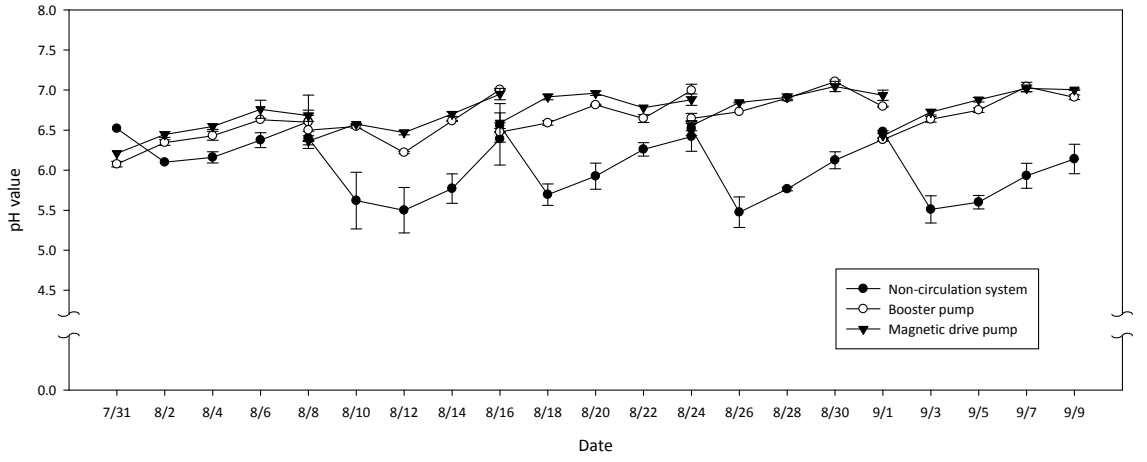

Fig 2. The variation of pH values in the hydroponic solution of the recirculation and non-circulation hydroponic systems, and the recirculation hydroponic system was driven by booster and magnetic drive pumps. 'Taoyuan No.1' was planted in the experiment from 23 Jul. to 9 Sep. 2014.

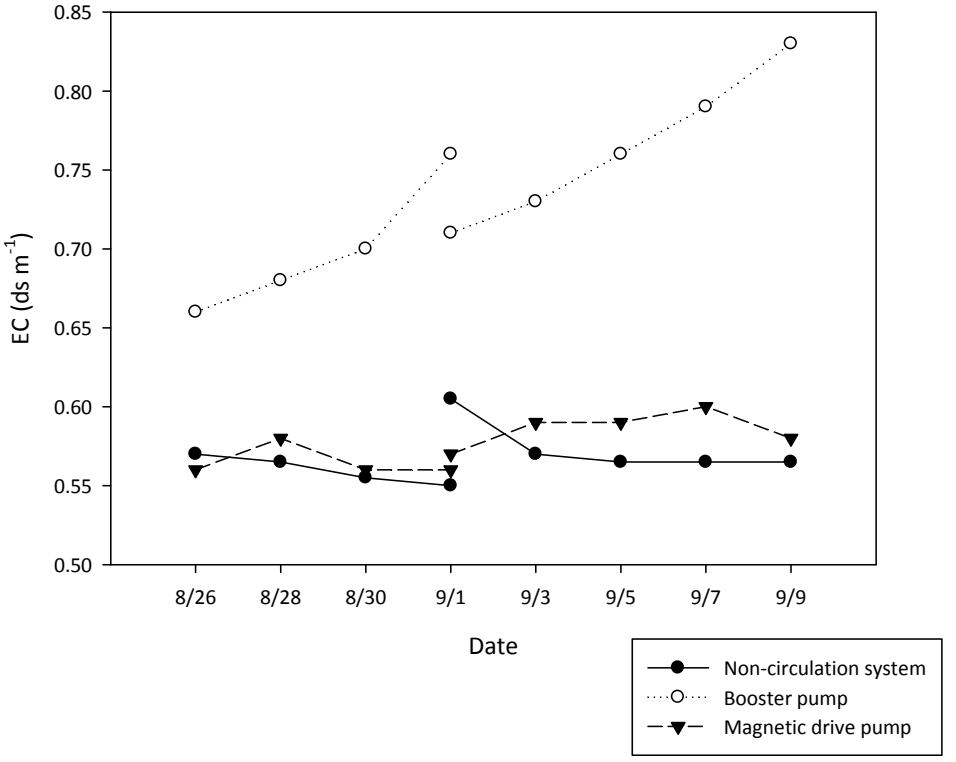

Fig 3. The variation of EC values in the hydroponic solution of the recirculation and non-circulation hydroponic systems, and the recirculation hydroponic system was driven by booster and magnetic drive pumps. 'Taoyuan No.1' was planted in the experiment from 23 Jul. to 9 Sep. 2014.

The nutrient consumption was not significant different between the 2 recirculation systems (Fig 4). There were severe solution splitting in the booster pump-recirculation system in the second week due to sudden increase of pressure; therefore, the consumption of second week was over calculated. The result also showed that current nutrient management resulted NO_3^- depletion and SO_4^{2-} accumulation at the end of Exp I.

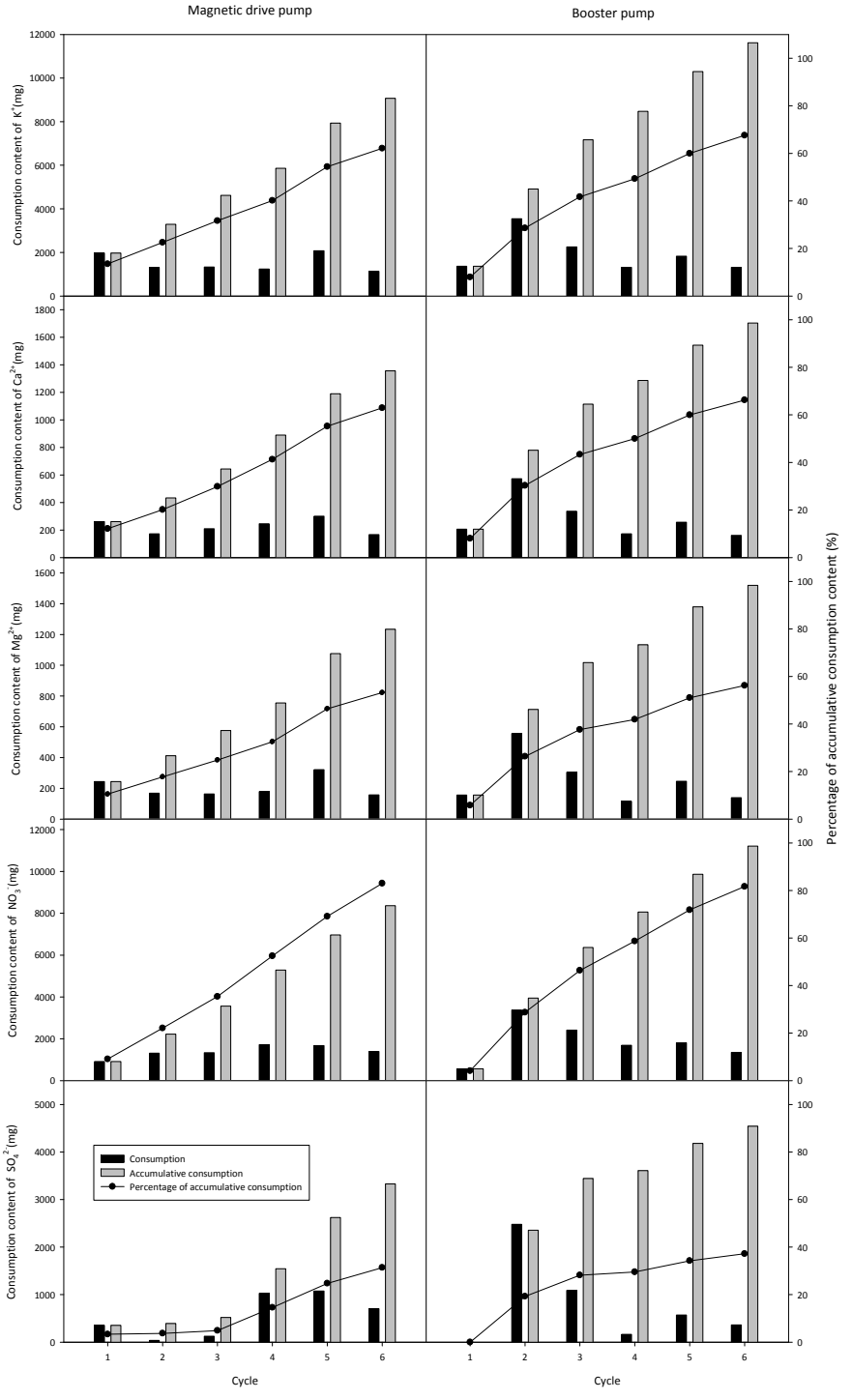

Fig 4. The ion consumption of each cycle and accumulative consumption in recirculation system. Recirculation hydroponic system was driven by booster pump and magnetic drive pumps. Each cycle was 8 days becaused the non-circulation system renewed its solution. ‘Taoyuan No.1’ was planted in the experiment from 23 Jul. to 9 Sep. 2014.

Modified Enshi solution increases daughter plant production

Enshi solution was modified to increase N content and decrease SO_4^{2-} content according to the result of Exp I, and the modified solution was designated as modified Enshi (ME). The effect of solution on daughter plant production was evaluated for 6 lots of harvest. There was no interaction between solution and harvest lots on leaf and runner formation, crown diameter, SPAD value, leaf area and daughter plant generation (Table 2). ME solution increased accumulated runner formation, leaf SPAD value and area, and daughter plant generation (Table 2 and Fig 5). Harvest lots significantly affected the parameters mentioned above. The total daughter plant production was significantly higher in ME (Table 3). Nearly all the daughter plants survived after 3 weeks of acclimation and can be used as healthy mother plants.

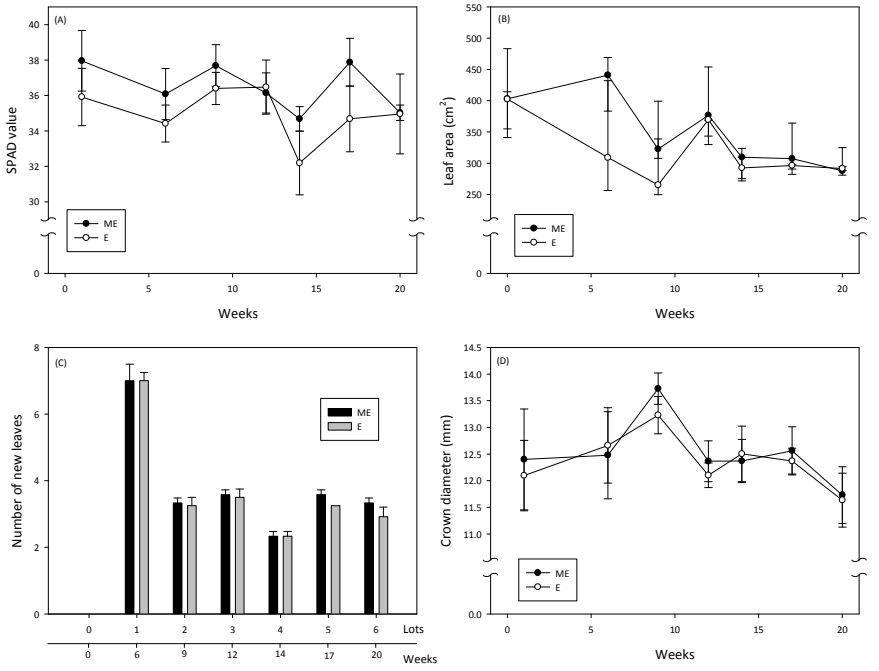

Fig 5. The effect of hydroponic solution on the growth of strawberry ‘Taoyuan No.1’. (A)The SPAD value of the youngest fully expanded leaf, (B) the leaf area, (C) the accumulative new leaves, and (D) the crown diameter of mother plant were recorded after daughter plant harvesting. In the recirculation hydroponic systems, the modified Enshi(ME) and Enshi(E) solution were tested and refreshed every 8 weeks. The experiment was conducted from 13 Feb. to 3 Jul. 2017.

Table 2. The analysis of variance (ANOVA) of two solution formula on daughter plants production in strawberry 'Taoyuan No.1' mother plant.

	Leaf number		Runner number		Crown diameter (mm)	SPAD value	Leaf area (cm^2)	Daughter plants
	Single harvest[w]	Accumulative	Single harvest	Accumulative				
Solution (S)[z]	NS	NS	NS	**	NS	**	**	*
Lot (T)[y]	***	***	***	***	***	**	***	***
S*L[x]	NS	NS	NS	NS	NS	NS	NS	NS

[z]Two treatment and each treatment was with 3 replicates. Each replicate was with 4 plants.
[y] The experimental duration was 140 days. There were 6 lots of harvest.
[x] Statistical analyses were conducted using ANOVA (Costat 6.2, CoHort Software, USA) and the means compared with LSD test with a significance level $p < 0.05$.
[w]The new leaves and runners generated from mother plants between harvests.

Table 3. The daughter plants number of strawberry 'Taoyuan No.1' mother plant growing under two solutions.

Harvest Lots[z]	Modified Enshi				Enshi			
	Daughter plants			Survival ramets[w]	Daughter plants			Survival ramets
	rooted[y]	un-rooted[x]	total		rooted	un-root	total	
1	57	5	62	61	58	4	62	62
2	65	22	87	87	63	9	72	72
3	56	14	70	70	52	12	64	64
4	50	7	57	N.D.[v]	52	5	57	N.D.
5	66	19	85	N.D.	59	16	75	N.D.
6	65	19	84	N.D.	65	18	83	N.D.
total	359	86	445a	N.D.	349	64	413b	N.D.

[z]Harvest the runner when the daughter plants cover the culture plane, and harvested 6 times.
[y]Daughter plants rooted in hydroponic system.
[x]Daughter plants rooted in the culture medium in greenhouse.
[w]The daughter plants survived and were ready to transplant to the field.
[v]Not determined: the daughter plants did not be evaluated in the greenhouse.

5. DISCUSSION

Replacing submersible pump with booster or magnetic drive pumps in DFT system, strawberry plants maintained healthy throughout the whole experimental period (Fig 1) indicated that pump type affected nutrient supplement in DFT system. The plants in the magnetic drive pump-recirculation system increased 18% of shoot weight and 21% of root weight (Table 1). Kitazawa *et al* (2005) suggested that the growth of strawberry plants in closed hydroponic system may be inhibited by their root exudates including lactic acid, benzoic acid, succinic acid, adipic acid and p-hydroxybenzoic acids. In addition, all the exudates inhibited root growth but only benzoic acid affected shoot growth. The deleterious effects of those organic acids might be alleviated by activated charcoal absorbing or electrodegradating (Asao et al., 2008; Kitazawa et al., 2005); however, the decrease in vegetative growth remained to be solved. The factor that hinder plant growth in submersible pump driven system was immediate and vanished by replacing driven power revealed that the cause was different from root exudates. The magnetic drive pump-recirculation system was selected for further study due to its stable pH and EC values (Fig 2 and 3).

Enshi solution composed both NO_3^- and NH_4^+. Plant root tends to absorb NH_4^+ first when both types of N exists in the nutrient solution and releases H^+ accompanying the absorption, as the result the solution pH would decrease (Ikeda, 1983). In current test, nearly all NH_4^+ was absorbed within 8 days in all systems tested (data not shown). Therefore, the pH of the non-circulation system dropped within the first 2 days after each solution renewing and climbing up in the following 6 days (Fig 2). In recirculation system, NH_4^+ concentration remained very low in the following weeks indicating the solution adjustment each week did not alter NH_4^+ concentration, and that can explain the maintain of pH value (6.2-7.0).

The ion consumption was more stable in magnetic drive pump-recirculation system (Fig 4). Since the NO_3^- supplement in weekly adjustment is less than weekly consumption, N source will be run out in 8 weeks in current solution management. On the other hand, SO_4^{2-} kept accumulating. For prolonging the recirculation period, a modified Enshi solution was formulated and tested for daughter plant production.

The vegetative growth of strawberry may be significantly affected by the ratio of NH_4^+/NO_3^- in nutrient solution (Tabatabaei et al., 2006). Under the situation of same concentration of N, the fertigation solution contained NO_3^- as sole N source or high NH_4^+ would resulted in less vegetative growth, and NH_4^+/NO_3^- between 25:75 and 50:50 may produce more leaf, higher fresh and dry weight and larger leaf area. In our hydroponic

system, the N concentration was increased in modified Enshi solution and its NH_4^+/NO_3^- was also modified from 7:93 to 17:83. The comparative study showed that modified Enshi solution resulted in higher SPAD value, larger leaf area, more runner and daughter plant production (Table 2). In the recirculation period, pH value may drop to 4 in the first 2 weeks due to higher NH_4^+/NO_3^-; however, no visible physiological difference between treatments was observed. Due to the variation of leaf area and crown diameter, the experiment was stopped at 6th lot of harvest.

In the magnetic drive pump-recirculation system, the daughter plant production was 13.48 and 12.52·m^{-2}·week·layer for modified Enshi and Enshi solution. Both the hydroponic rooted and unrooted daughter plants grew well in pots and could be used as mother plants of next generation or transplanted to the field for fruiting. We concluded that recirculation hydroponic system in closed plant factory can be used as a bioreactor for daughter plant production and modified Enshi solution may increase 8% of yield.

6. Literature cited

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