Development of a Greenhouse Nutrient Recycling System for Tomato Production in Humid Tropics

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ABSTRACT

Generally it is not customary to have a nutrient recycling system for the tropical poly-net greenhouses. The main reason is the cost involved. However, due to recent growing environmental concerns, efforts were made in this study to develop a simple but effective nutrient recycling system.

Tomato (*Lycopersicon esculentum Mill.*, var. FMTT-260) plants were grown under two identical poly-net greenhouses. One greenhouse was equipped with nutrient recycling system while other without nutrient recycling as a control. The amount of water and nutrient saved were assessed, and plant growth performance in both greenhouses was compared.

Studies revealed that recirculation of nutrient solution could save 31.5% of total irrigation water. Among the measured major plant essential elements, the potential saving of nitrogen, phosphorus, potassium and calcium were 29.87%, 31.44%, 29.83% and 28.16% respectively. The break-even of the additional cost of nutrient recycling was less than five crop productions over a given area. The total crop yield of the closed fertigated greenhouse was almost similar to that of open fertigated greenhouse. Plant growth parameters (plant height, stem diameter and leaf area index), average size and weight of fruits, and fruit qualities (marketable fruits, moisture content, brix, pH and firmness) of closed fertigated greenhouse were also almost similar to that of open fertigated greenhouse. Due to recycling, the water productivity was increased by 45.7%.

Keywords: Tomato, nutrient recycling, water and nutrients saving, yield, fruit qualities

1. INTRODUCTION

Some of the driving force for the development of a closed fertigation system includes restricting environmental laws and regulations aiming to reduce nutrient leaching to the environment; significant savings of water and nutrients; better control of nutrient supply; and reduced risk of ground water contamination (Magen, 1999). In the Netherlands, law prohibits growers to let the excess nutrients solution run off because of surface and ground water pollution with nutrients and pesticides (Runia and Amsing, 2001).

The supply of water and nutrients is equal to the uptake by the crop in closed growing system, which prohibits the losses (Voogt and Sonneveld, 1996). Recycling the nutrient solution after collection includes mixing over drain with fresh water; adjusting the EC and pH of the solution and its composition; and disinfection in some cases (Khosla, 2004). But, variations in water and nutrient uptake makes the recycling system complicated. If water uptake is higher than nutrients, EC will build up and vice versa (Magen, 1999). The horticultural problems between the transitions from open to closed fertigation systems includes salinity and toxic ion concentration increase in recycled solution, nutrients uptake disorders under high salinity conditions, and root pathogens proliferation (Bar-Yosef et al., 2000). In central and northern Europe, the widely used nutrient recycling technique is automated mixing of tap water and drain solution up to a particular EC and subsequent addition of constant quantity of concentrated stock solutions to reach the target EC in the irrigation solution (Sevvas, 2001).

Crop absorbs about 50% of fertilizer and remaining is leached. Similarly, crop used only 70% of the water for growth and transpiration (Choi et al., 2001). The nutrient recycling is widely used in hydroponic and nutrient film techniques (NFT). The drainwater from the soil can be also used for recycling (Runia and Amsing, 2001).

Numerous trials have demonstrated that the bio-sand filters are effective in removing *Phytophthora* spp. and *Pythiurn* spp. from the over drain while high efficiency was recorded against *Fusarium spp., Cylindrocladium, Verticillium dahliae, Thielaviopsis,* and *Xanthomonas* bacteria (Anon., 1999). Other advantages of slow sand filtration (SSF) over heat treatment, ozonation and ultraviolet (UV) treatment includes no need for chemicals or technical instrumentation; low energy consumption; minimal maintenance; can be built and installed by laymen; and adaptability in components and applications (Barth, 1998).

The finest sand (0.15 - 0.35 mm), which also presents a physical barrier to the passage of spores of plant pathogens, was found the most efficient to control *Fusarium sp*. in the Netherlands. At slow rates (200 lit h^{-1} m^{-2} surface area of filter) of water filtration, pathogenic bacteria and fungi; and some viruses were killed by micro organisms living in the filter where the biological activity extends through the top layer of the filter to a depth of approximately 40 cm (Barth, 1998).

The growing environmental awareness in tropical countries to reduce soil and water pollution is compelling greenhouse growers to use cost effective techniques to reuse the nutrients loop in drainage water. This study was aimed to develop a nutrient recycling system and to evaluate the amount of water and fertilizer saved; and analyze the presence of pathogens. The study was also focused on the comparison of growth and development of plants; yield and fruit qualities between the open and closed fertigation system (Dhakal, 2005).

2. MATERIALS AND METHODS

Experiments were conducted at Protected Cultivation Project site on Asian Institute of Technology (AIT) campus, Bangkok, Thailand. Two identical east to west oriented greenhouses (20 × 10 × 6.4 m) were used for the experiments. UV-stabilized polyethelene (PE) film was used to cover greenhouse roof, gables and lower part of the sidewalls (up to a height of 0.8 m above the ground). The sidewalls and the ventilation opening on the roof were covered with 40 mesh sized insect proof nets.

On 8 December 2004, 360 tomato (*Lycopersicon esculentum* – var. FMTT-260) seedlings were transplanted into black plastic pots which were placed in six rows (60 pots per row) in each greenhouse. The soil substrate was composed of 28% organic matter. The pH of substrate was 5.3 and the texture was 30%, 39% and 31% of sand, silt and clay respectively.

Automatic drip fertigation system was used in both greenhouses to irrigate the tomato plants. Dosatrons were used to inject an appropriate amount of nutrients from plastic tanks into main irrigation water supply line. 2.5 kg hakaphos (N 6, P_2O_5 12, K_2O 36, MgO 3, B 0.025, Cu 0.01, Fe 0.07, Mn 0.04, Mo 0.04 Zn 0.025%) was mixed with 100 liters of water and the tank was fitted with dosatron set at 1.5% (to add 1.5 liters of nutrient solution per 100 liters of irrigation water). Similarly, 1.8 kg of calcinit (N 15 and CaO 27.5%) was mixed with 100 liters of water and the tank was fitted with dosatron set at 3.5%. Drippers of 2 lit h^{-1} capacities were used to distribute fertigation solution. The electrical conductivity of the fertigation solution was set at 1.5 mS cm^{-1} and the pH was 6.5. The solenoid valve controlled the overall fertigation, which was attributed to solar radiation.

Plastic tank of 200 liters capacity was buried outside the greenhouse to collect and recycle the over drain solution. The level control switch in over drain tank was set in such a way that submersible pump sent 165 liters of over drain solution at a time to bio-sand filter (BSF) through fast sand filter and flowmeter. Flowmeter (serie FCH-34, ± 2% accuray) was used to measure the amount of fertigation and over drain solution. The filtered over drain solution was allowed to flow gravitationally from BSF to the 500 liters capacity conditional tank where the electrical conductivity was adjusted with the set value and sent to the header tank of 1000 liters capacity by the submersible pump. The adjustment of EC was done by adding irrigation water or by proportionately mixed concentrated fertilizer (hakaphos and calcinit) solution. Figure 1 shows the outline of fertigation and nutrient recycling system.

The BSF, disinfection unit for pathogens, was made from a 60 cm diameter and 170 cm high plastic tank having 2.54 cm inlet and outlet positioned 5 cm from top and bottom respectively. The outlet of the filter was designed in such a way that there was always standing water of 10 cm above the top layer of sand. The outlet of 2.54 cm from 13 cm top was also made for overflow which was connected to the 200 liters capacity plastic tank. Layers of gravel, coarse, medium fine and fine sand of depths 10, 10, 25 and 35 cm respectively were put in the tank from the bottom of the tank. Figure 2 shows the fast sand filter and the schematic diagram of BSF.

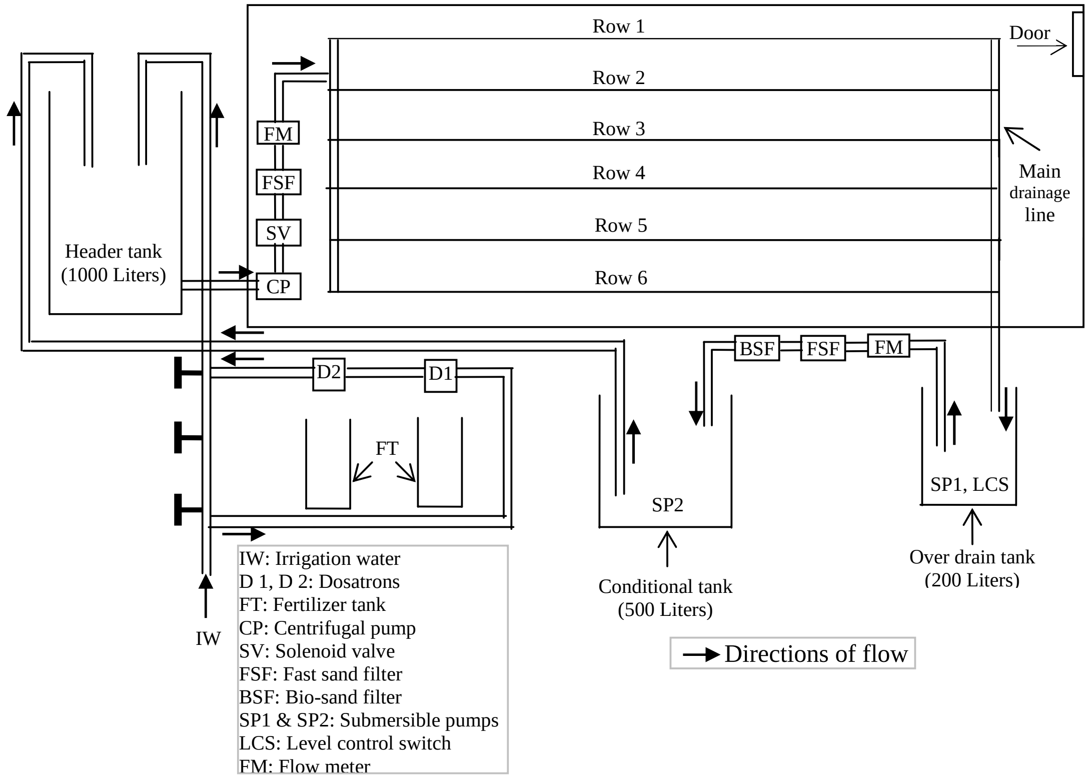


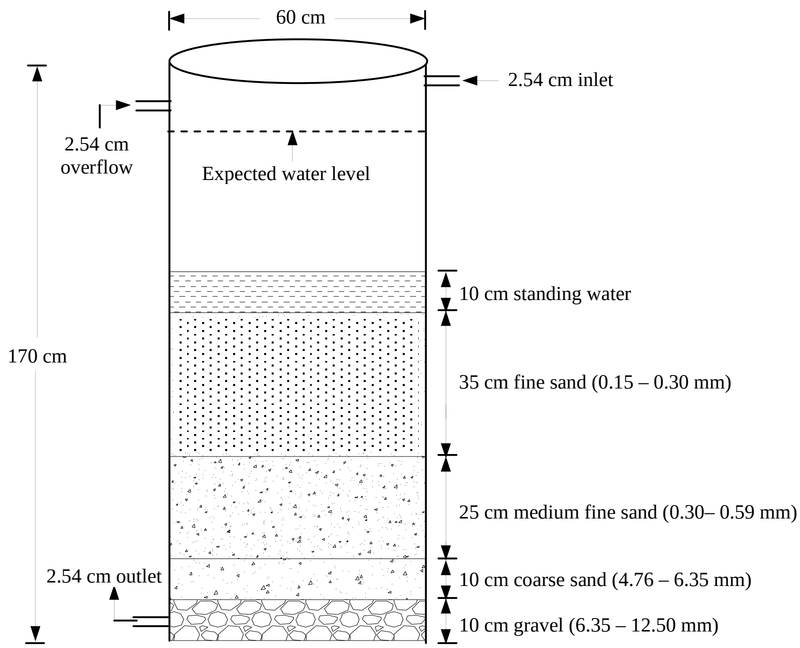
Figure 1. Outline of fertigation and nutrient recycling system

After transplanting, several climatic parameters were recorded inside the greenhouses. The daily volume, EC, and pH of fertigation and over drain solution of the closed fertigated greenhouse and weekly nutrient concentration of fertigation and over drain solution of both greenhouses were measured. Portable EC meter (LF 91) and pH meter (HANNA, HI 8424) were used to measure EC and pH respectively. Similarly, spectrophotmer (Jenway 6300) and flame photometer (Jenway PFP7) were used to measure nitrogen and phosphorus; and calcium and potassium respectively. Infestation of pathogens in over drain and filtered over drain were also analyzed on a weekly basis. The quantification procedure (Dilution Spread Plate) for total bacteria and fungi were NGA (Nutrition Glucose Agar), and Martins medium and PDA (Potato Dextrose Agar) + rifampicin (antibiotic) respectively. Plant height and stem diameter were measured from the date of transplanting (DOT) to final harvesting. Meter tape and vernier calipers were used to measure plant height and stem diameter respectively. Digital area meter (LI 3100) was used to measure leaf area (LA) until nine weeks after transplanting (WAT) and leaf area index (LAI) was calculated. Plant height, stem diameter and LAI were also measured on a weekly basis. Plant height and stem diameter were measured from six randomly selected samples from each of four inner rows whereas, the LA was measured of three randomly selected samples from four inner rows.

A total of five harvestings were done on a weekly basis starting from 65 days after transplanting (DAT). The harvested fruits were separated, weighed, counted, and graded. Digital balance (Scatex SBA 51) and vernier caliper were used to measure the weight and diameter of the fruits respectively. Six different color stages of tomato ripening, categorized by United States Standards for Grades of Fresh Tomatoes were separated visibly. The moisture content, brix and pH of fruits of each harvest were determined. The brix and pH of

15 days stored tomatoes; and the firmness of fresh and 15 days stored fruits of the third harvest were also determined. The storage temperature and relative humidity were 25 ºC and 65% respectively. Six samples from each of four inner rows were randomly selected for the above measurements. For moisture measurement, samples were dried in the air oven at 75 ºC until constant weight was obtained. The brix and pH were determined by using hand refractrometer and pH meter respectively, whereas firmness was measured by Lloyd Texture Analyzer. The mean comparison was done by students t-test to analyze the effect of treatments. Water productivity and the break-even of the additional cost of recycling system were also analyzed.

2a: Fast sand filter



2b: Schematic of designed bio-sand filter

Figure 2. Sand filters

3. RESULTS AND DISCUSSION

3.1 Calculation of Over Drain Solution

The microclimate inside the greenhouses was almost similar. The quantity of fertigation and over drain solution of closed fertigated greenhouse varied from 0.86 to 2.92 and 0.07 to 1.44 liters plant^{-1} day^{-1} respectively. The average volume of fertigation and over drain solution was 1.86 and 0.59 liters plant^{-1} day^{-1} respectively. Figure 3 shows the variation of fertigation and over drain solution. The over drain was 31.5% (9.94 m^3 ha^{-1}) of the total fertigation solution. This confirmed the conclusion by Magen (1999) that the percentage of over drain could be up to 40% of total fertigation solution.

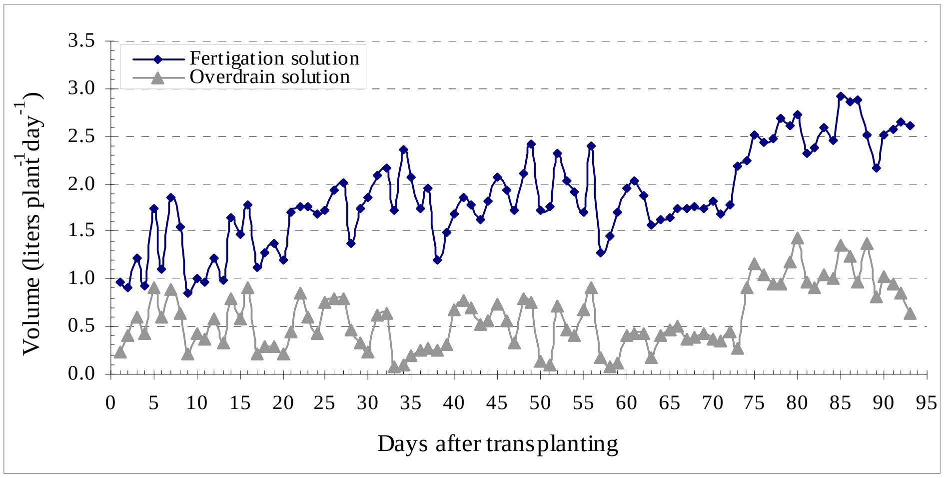


Figure 3. Amount of fertigation and over drain solution of closed fertigated greenhouse

3.2 Changes in EC and pH Values

The average EC of fertigation and over drain solution was 1.54 and 2.11 mS cm^{-1} respectively. Similarly the average value of pH of fertigation and over drain solution was 6.41 and 6.29 respectively. Figures 4 and 5 show the variation of EC and pH respectively of a closed fertigated greenhouse. EC values in the fertigation solution sometimes varied because of pressure difference of irrigation water. Higher EC values in the over drain were due to higher water uptake by plants as described by Magen (1999) but very high initial (until first week of transplanting) EC contents of over drain was due to the higher salinity of the substrate. The possible reason of low pH in the over drain solution is the formation of organic acid.

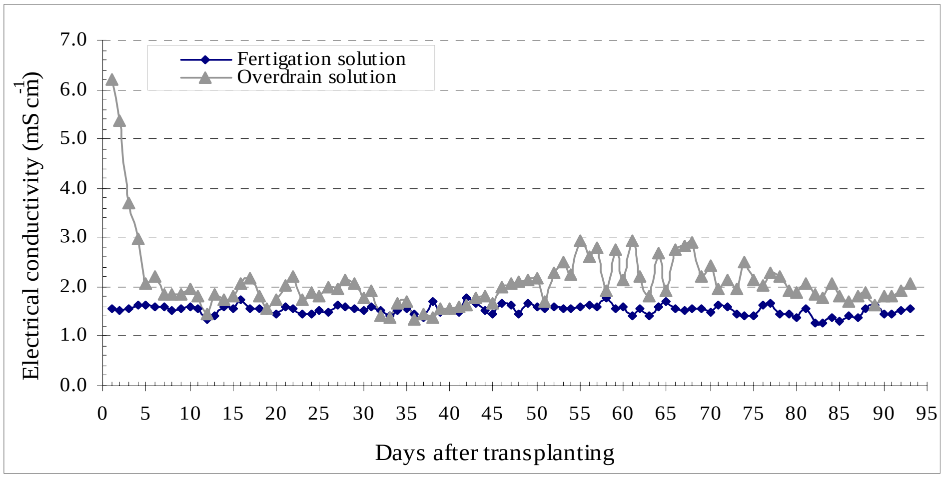


Figure 4. Daily EC of fertigation and over drain solution of a closed fertigated greenhouse

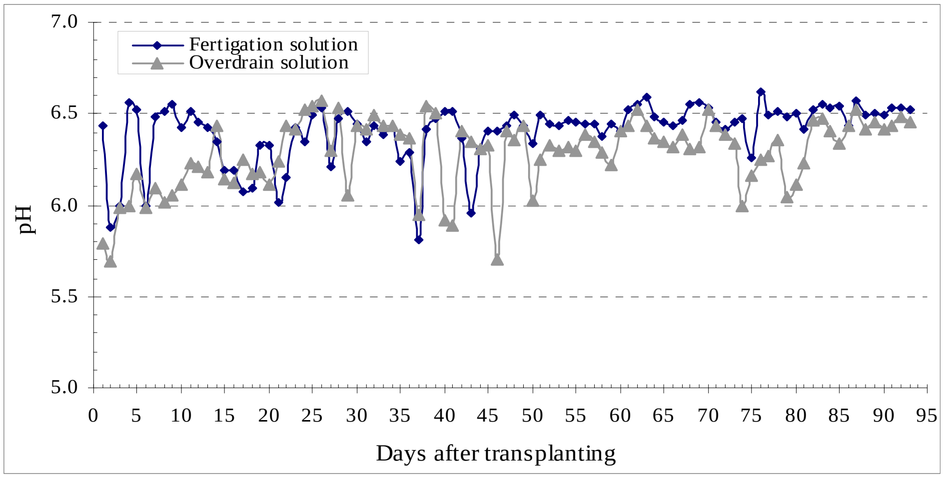
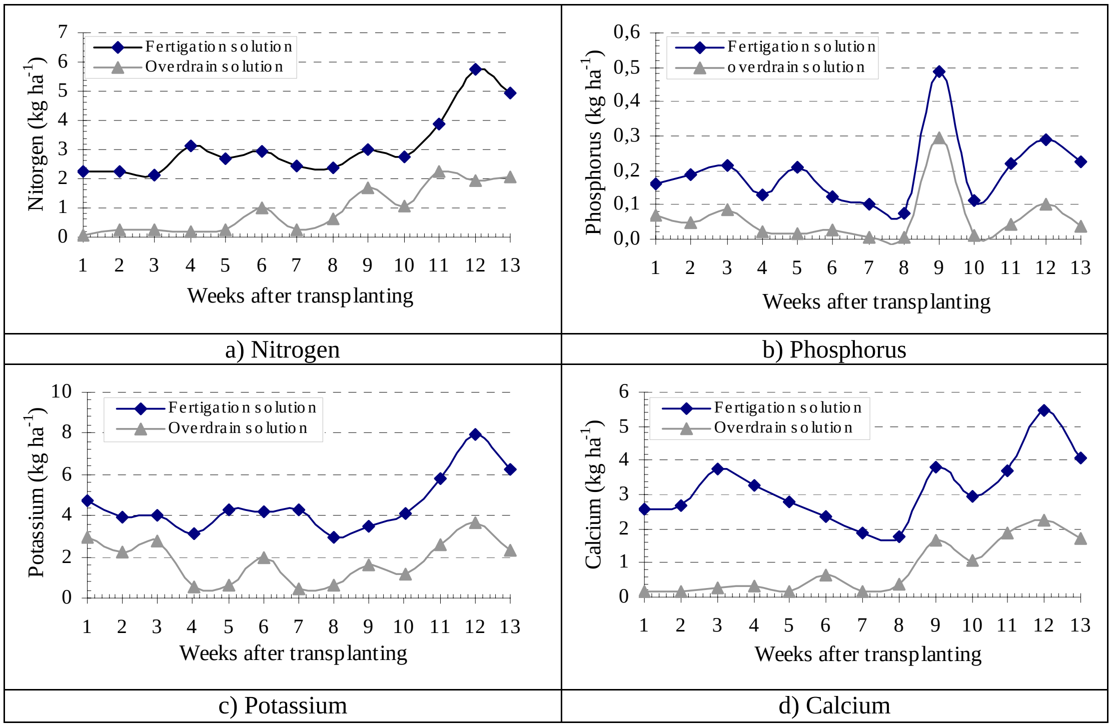


Figure 5. Daily pH of fertigation and over drain solution of a closed fertigated greenhouse

3.3 Variation in Nutrient

The variation of nutrient concentration in the fertigation solution of closed fertigated greenhouse was observed. The average actual concentration of nitrogen, phosphorus and potassium were less whereas the average actual concentration of potassium was higher than the set value. The lower concentration of nitrogen might be the reason that nitrogen can lose through the gaseous form either by volatization as ammonia or denitrification (Prasad and Kumar, 2001). The possible reason for less phosphorus and calcium might be the formation of precipitation of calcium phosphate. The possible reason for higher potassium is that it is not sufficiently soluble to be taken readily by plants as reported by Tiwari (2003). The possible reason of 1.5 mS cm^{-1} EC might be due to the non-measured nutrients. Figure 6 shows the nutrient concentration in fertigation and over drain solution of closed fertigated greenhouse.



a) Nitrogen — b) Phosphorus — c) Potassium — d) Calcium

Figure 6. Concentration of nutrient in fertigation and over drain solution of a closed fertigated greenhouse

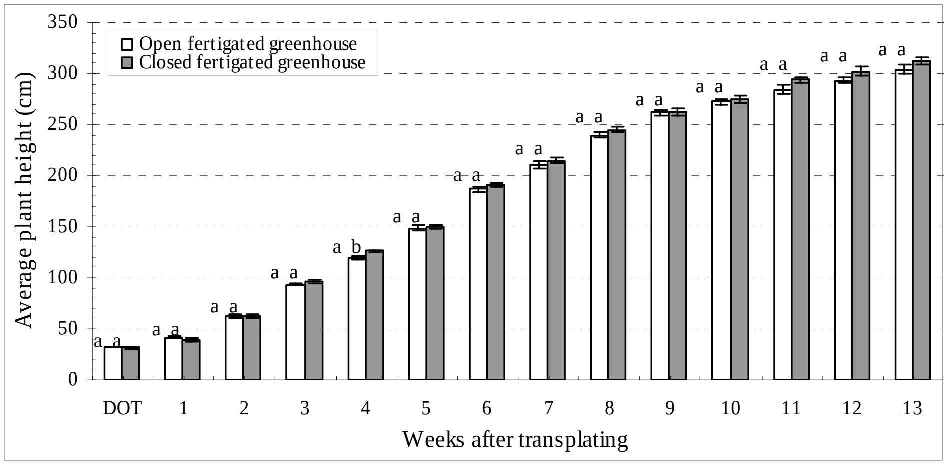
The potential saving of nutrients was calculated from the open fertigated greenhouse; however, varying water pressure of the irrigation water also affected the concentration of nutrients in fertigation solution. The saving of nitrogen, phosphorus, potassium and calcium was estimated to be 29.87, 31.44, 29.83 and 28.16% respectively. Tuzel et al. (2001) concluded that closed fertigation system with substrate could save nutrients up to 34%.

3.4 Analysis of Pathogens

The lab analysis showed that the pathogenic fungi (*Pythium*, *Fusarium* and *Pythophthora)* and bacteria *(Ralstonia solanacearum)* were absent in the over drain and filtered over drain solution.

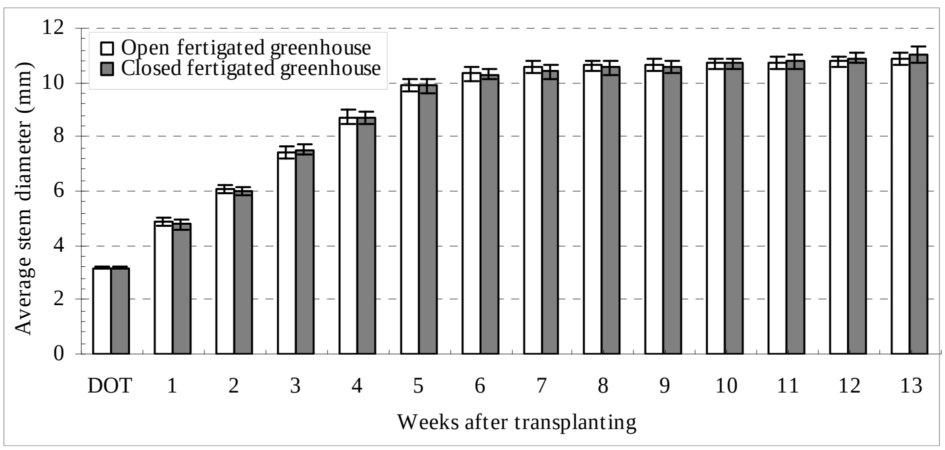
3.5 Plant Growth Characteristics

Plant growth parameters (plant height, stem diameter and LAI), shown in Figures 7 to 9 revealed that these parameters (except higher plant height on fourth WAT of closed fertigated greenhouse) were similar in both greenhouses. At ninth WAT, the LAI was 2.64 and 2.75 for open and closed fertigated greenhouse respectively. As LAI was measured until 9 weeks after transplanting, it was lower than 3 to 5 (for matured crops) as reported by Allen et al. (1998).



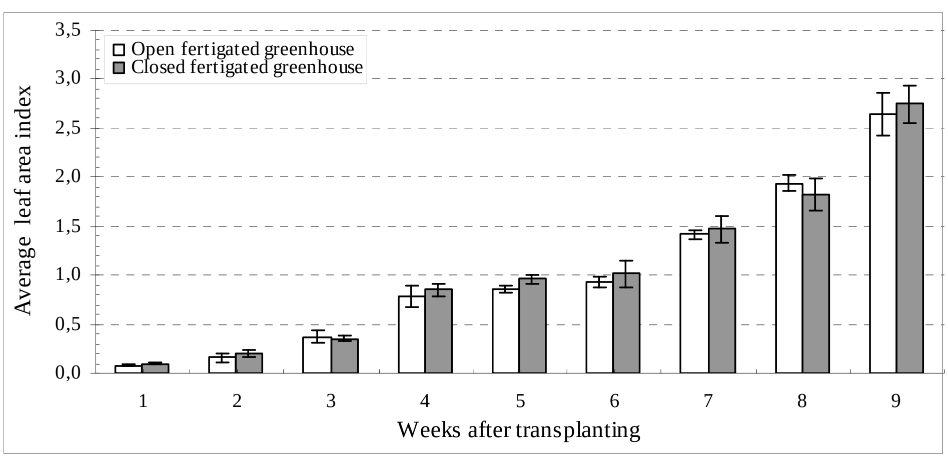
Significant differences (p<0.05) between the treatments are indicated by different letters within one couple of bars

Figure 7. Average plant height



No significant differences (p<0.05) were observed between the treatments

Figure 8. Average stem diameter

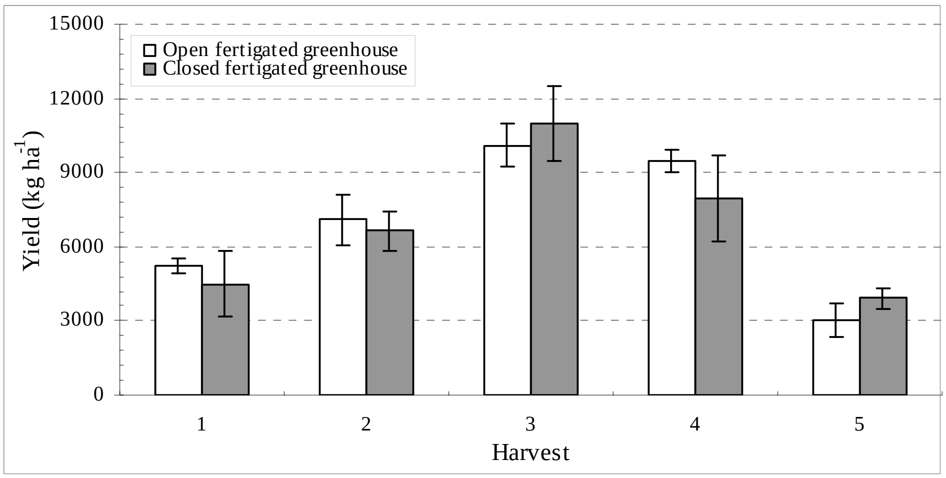


No significant differences (p<0.05) were observed between the treatments

Figure 9. Average leaf area index

3.6 Yield and Fruit Characteristics

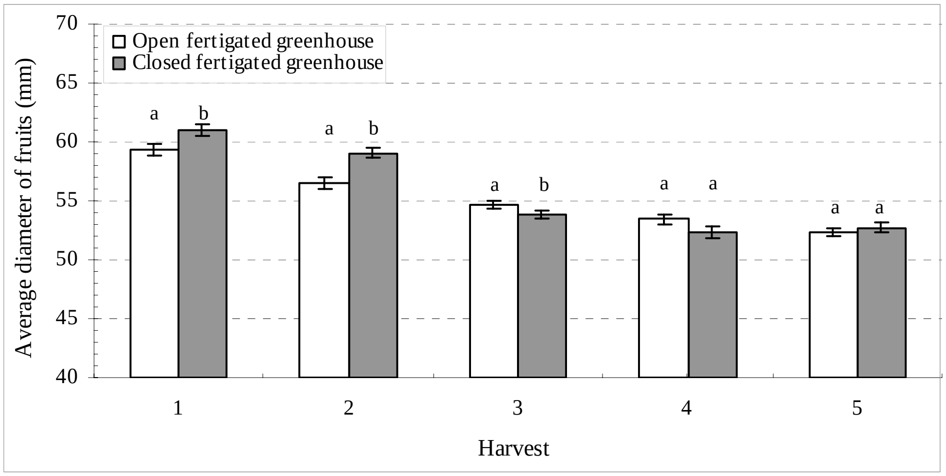
The fruit yield, shown in Figure 10, was almost similar in both greenhouses. Gul et al. (2001) and Tuzel et al. (2001) found similar results in their studies. The total estimated yield of open and closed fertigated greenhouses were 34.90 and 33.98 t ha^{-1} respectively. Non-marketable fruits were separated on the basis of weight less than 50 grams, disease infected, cracked, suffered from blossom end rot and of irregular shape. Marketable fruits of fourth harvest were significantly higher in open fertigated greenhouse. Peak was reached in the closed fertigated greenhouse but decline began earlier. Thus for open fertigation system, the marketable yield was found significantly higher in the fourth harvest. The average percentage of non-marketable fruits of total harvest was 9.65 and 12.62% for open and closed fertigated greenhouse respectively.



No significant differences (p<0.05) were observed between the treatments

Figure 10. Yield of tomato

The total numbers of marketable fruits were 4,255 and 4,201 in open and closed fertigated greenhouse respectively. Because of higher marketable yield, the total number of marketable fruits of open fertigated greenhouse was significantly higher in the fourth harvest. The average diameter of marketable fruits of open fertigated greenhouse was significantly lower in the first and second harvest but was higher in the third harvest as shown in Figure 11. The range of diameter of marketable fruits was 52 to 59 mm and 53 to 61 mm for open and closed fertigated greenhouses respectively, which can be categorized as small to medium as defined by United States Standards for Grades of Fresh Tomatoes (1997). The average weight of fruits was almost similar.

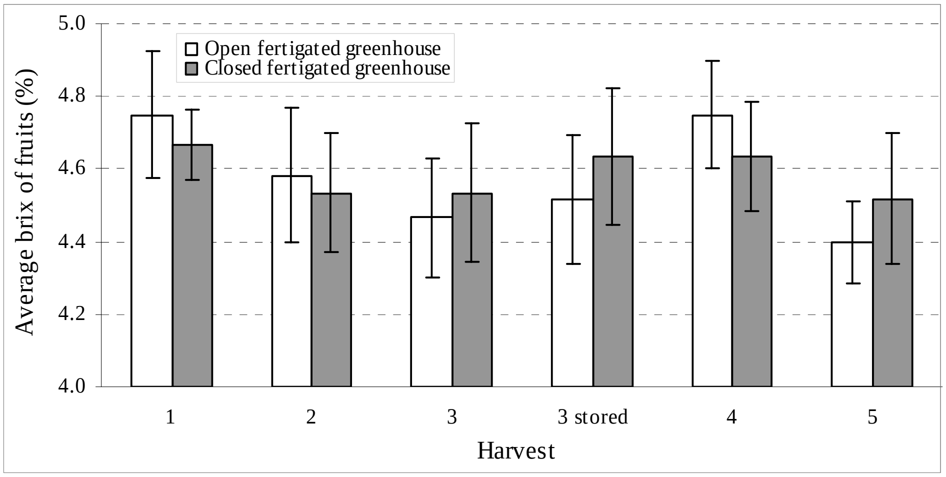


Significant differences (p<0.05) between the treatments are indicated by different letters within three couple of bars

Figure 11. Average diameter of fruits

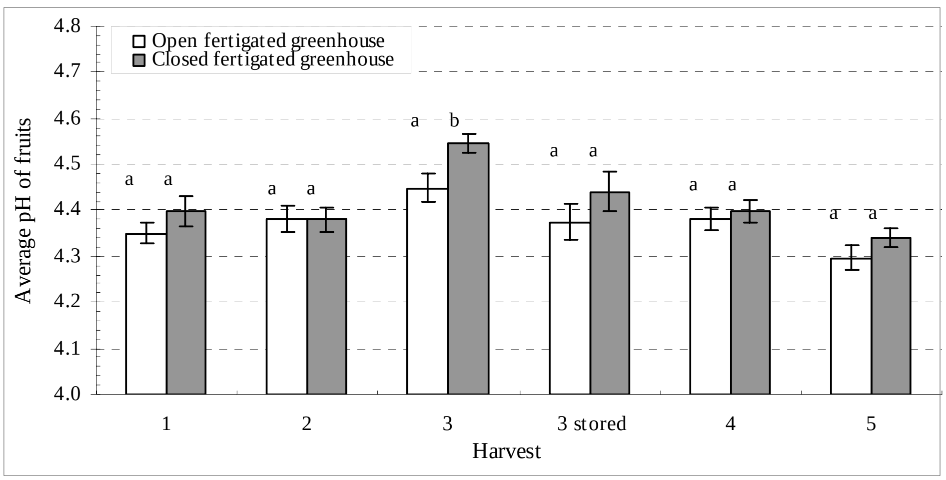
The average moisture content of the freshly harvested fruits ranged from 93.58 to 94.06% and 93.46 to 94.03% for the open and closed fertigated greenhouse respectively. Water content of tomato fruit is about 93 to 94% (Stevens, 1985), and varies with variety and characteristics of growing media (Gould, 1983). The moisture content of fruits of second harvest of closed fertigated greenhouse was found significantly lower. The average brix of freshly harvested fruits, as shown in Figure 12, ranged from 4.40 to 4.75 and 4.52 to 4.67% for open and closed fertigated greenhouse respectively and was almost similar in both greenhouses. The higher brix was also noticed with the degree of fruit ripening. The brix of 15 days stored tomatoes was higher due to physiological changes but the increment was not significant. The brix of the fruits falls in poor to average group as categorized by Harrill (1998).

The average pH of fruits ranged from 4.30 to 4.45 and 4.34 to 4.55 for open and closed fertigated greenhouses respectively. The pH of the fruits of closed fertigated greenhouse was always higher but the difference was significant only for third harvest as shown in Figure 13. A decrease in pH was noticed with the degree of fruit ripening. Lower pH was noticed in stored fruits. The observed pH values of the fruits indicated that tomato as an acidic fruit as described by Gould (1983). Similarities in fruits qualities confirmed the findings by Gul et al. (2001) that intermittent and continuous circulation of nutrient solution had no significant differences in fruit quality characteristics grown in NFT.



No significant differences (p<0.05) were observed between the treatments

Figure 12. Average brix of fruits



Significant differences (p<0.05) between the treatments are indicated by different letters within one couple of bars

Figure 13: Average pH of fruits

Figure 14 shows the comparison of average firmness of fresh and stored tomatoes of third harvest. The firmness decreased with the degree of fruit ripening due to the action of pectin methylesterase and polygalacutonose pectinase enzymes as mentioned by Parera and Baldwin (2001); and Wendy and Barrett (2002). When fruit ripens to full maturity, protopectin changed to pectin and fruit becomes soft (Gould, 1983). Due to storage, the firmness of the fruit decreased to 73 and 74.5% of open and closed fertigated greenhouse respectively.

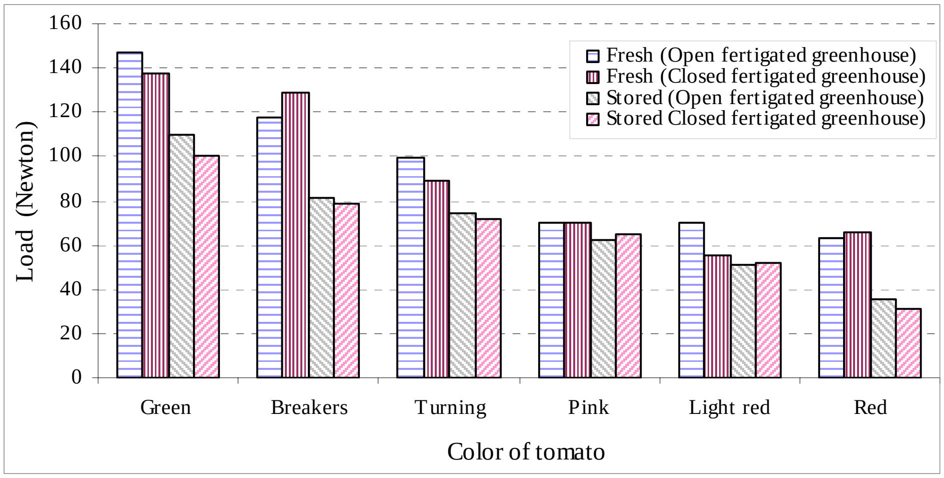


Figure 14: Comparison of firmness of freshly harvested and 15 days stored tomatoes

3.7 Distribution Uniformity, Emitter Flow Rate and Water Productivity

The average distribution uniformity and emitter flow rate, measured on 2, 46 and 92 DAT was about 95 and 93% respectively in both greenhouses. Due to recycling, the water use efficiency was increased by 45.7%.

3.8 Cost Analysis

The total set up cost of nutrient recycling was US$ 305 and the total saving per crop production was US$ 80. The maintenance and operating cost of recycling system was considered 5% of the total cumulative cost of each crop production. The estimated break-even of the additional cost of nutrient recycling was less than five crop productions.

4. CONCLUSIONS

The results showed that recycling of nutrient solution could save 31.5% irrigation water. The potential saving of nitrogen, phosphors, potassium and calcium was 29.87, 31.44, 29.83 and 28.16% respectively. The infestation of pathogens (fungi: *Pythium, Fusarium* and *Pythophthora species,* and bacteria: *Ralstonia solanacearum*) were not found in the over drain and filtered over drain solution.

The growth and development trend of tomato plants in both systems were similar. The total estimated yield of open and closed fertigated greenhouse was 34.90 and 33.98 t ha^{-1} respectively and the difference was statistically insignificant. The average non-marketable tomatoes were 9.65 and 12.62% from open and closed fertigated greenhouse. The total weight and number of marketable fruits were significantly higher only in the fourth harvest of open fertigated greenhouse. The average diameter of marketable fruits of open fertigated greenhouse was significantly lower in the first and second harvest but higher in the third harvest.

The overall moisture content, brix and pH of tomato fruits were not statistically significant for both greenhouses. The firmness of the stored fruits of open and closed fertigated greenhouse decreased to 73 and 74.5% of the original respectively. Due to recycling, water productivity was increased by 45.7%. The estimated break-even for the additional cost of nutrient recycling was less than five crop productions.

As yield, and nutrients and water savings showed positive effects, the application of a closed fertigation system was asserted. The established simple nutrient recycling system can be considered as a practical alternative to the conventional cropping practice using open fertigation.

5. ACKNOWLEDGEMENTS

The authors are grateful for the support received from the collaborative Protected Cultivation Project between the Hannover University, Germany and Asian Institute of Technology, Thailand.

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ABBREVIATIONS

B	Boron	Mn	Manganese
BSF	Bio-sand filter	Mo	Molybdenum
CaO	Calcium oxide	mS cm^{-1}	MilliSiemens per
Cu	Copper	centimeter	
DAT	Days after transplanting	N	Nitrogen
DOT	Date of transplanting	NFT	Nutrient film technique
EC	Electrical conductivity	P_2O_5	Phosphorus pentoxide
Fe	Iron	UV	Ultraviolet
K_2O	Potassium oxide	var.	Variety
LAI	Leaf area index	WAT	Weeks after transplanting
lit	Liter	Zn	Zinc
Mgo	Magnesium oxide		