

**HYDROPONICS SYSTEM FOR WASTEWATER TREATMENT  
AND REUSE IN HORTICULTURE**

By

Noraisha Oyama

BEnvSc

This thesis is presented for the degree of Doctor of Philosophy,  
Murdoch University, Western Australia

October 2008

## DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work, which has not previously been submitted for a degree at any tertiary education institution.

Noraisha Oyama

## LIST OF PULICATIONS

### Published papers

1. Oyama, N., Nair, J. and G. E. Ho (2005). Recycling of Treated Domestic Effluent from an On-site Wastewater Treatment System for Hydroponics. *Water Science and Technology* **51**(10): 221-220.
2. Oyama, N., Nair, J. and Ho, G. E. (2008). Utilising an integrated wastewater hydroponics system for small scale use. *Water and Environmental Management series*. 13-23.
3. Nair, J., Levitan, J. and Oyama, N. (2008). Zinc and copper uptake by silver beet grown in secondary treated effluent. *Bioresource Technology*. **99**: 2537-2543.

### Papers presented at conferences

4. Oyama, N., Nair, J. and Ho, G. E. (2004). Wastewater Hydroponics for Horticulture. *IWA World Water Congress and Exhibition*. Marakech, Morroco, September 19-24 2004.
5. Oyama, N., Nair, J., Mathew, K. and G. E. Ho. (2005). Wastewater Hydroponics for Urban Food Production. *1<sup>st</sup> IWA-ASPIRE (Asia Pacific Regional Group) Conference & Exhibition*. Singapore, July 10-15 2005.
6. Oyama, N., Nair, J. and Ho, G. E. (2008). Comparison Of Pathogen Die-Off Patterns Of Tomatoes Grown In Two Hydroponics Systems. *1st International Conference on Technologies & Strategic Management of Sustainable Biosystems*. Fremantle, 6-9 July 2008.

## ACKNOWLEDGEMENTS

I couldn't have done this without the support from a large group of people. There are a number of people I would like to acknowledge, who have helped me in various ways;

I would like to begin by giving a special thanks to my principal supervisor, Dr. Jaya Nair for guiding me through this whole process (I know there were times that I frustrated Jaya, I am glad she saw me through the whole process) also my gratitude to my other supervisors Prof. Goen Ho and Prof. Richard Bell.

There are quite a number of people who helped me during the early stages of my research from the Environmental Technology Centre, Dr. Martin Anda, Dr. Stewart Dallas, Dr. Kuruvilla Mathew and Dr. Peter Stuart. My fellow research students at the ETC, Robbie Cocks, Sergio Domingos, Robert Hughes, John Hunt, Jason Levitan and Beth Strang, the frequent coffee breaks helped (I think). The greenhouse would not have been possible without the assistance of Mick Sherriff, Karen Mckensie, the MAD team, the "Green Reserves" and "Work for the Dole" teams.

I used to walk into the offices of Colin Ferguson, Heather Gordon, Frank Salleo whenever something went wrong or I had a question. Thanks for your patience when I did. The technicians, Steven Goynich and Phil Good for letting me use equipment at short notice. There are a few research students who gave me advice on various things (mainly computers) that helped my journey through this immensely, Davina Boyd, Rory Donnelly, Jatin Kala and particularly Wendy Vance for allowing me to use her computer to finish off my graphs (every time it was supposed to be the last time!!).

I have had the opportunity to chat with many of the academics in Environmental Science, about various things and they have also given me the opportunity to teach Prof. Nick Costa, Prof. Tom Lyons, Ass. Pro. Bailey, Assoc. Prof. Frank Murray, Assoc. Prof. Mike Calver, Assoc. Prof. Peter Dingle, Dr. Catherine Baudains, Mr. Ross Lantzke, Dr. Karin Strehlow and Dr. Marian Kemp, the experience has been incredible.

The staff at the Graduate Centre, particularly Karen Olkowski, Emma Thorp and Assoc. Prof. Graham O'Hara, have been very helpful during many stressful times.

The many lunch and dinner discussions were great with a number of academics, research staff and research students. It was good to know that I was not the only one going through interesting times.

Now to my family and friends in Australia, Ahmed, Jonelle, Kel, Laura, Mandi, Mel, Naj, Simone, Sooraj, Stanton, Mums & Dads Gray, Lorantas and Sommerford, Unc. Sam and Yvonne who have assisted me both physically and emotionally, I am grateful for your support. The rest of my family and friends in Australia, Kenya and overseas have also contributed to this journey, in particular, Amma, Abaji and A. Raj.

My family in Japan particularly Mum, Emma, Sakai and my grandparents have given me an immeasurable amount of support. Finally, to Lolo, who has gone insane during this process, which has allowed me to retain some level of my sanity, I cannot put into words how much your support means to me.

## ABSTRACT

As human population increases, the need for water increases in domestic, agricultural, industrial and urban sectors. Wastewater reuse after treatment is gaining acceptance world wide, as availability of fresh water sources decreases. However, it is also important to point out social and cultural differences that still exist in different parts of the world including those where reuse of wastewater for food production or any domestic use is not yet acceptable. The major concerns with effluent reuse are primarily its impact on human health and environmental risk. As a result, effluent reuse should be undertaken with caution after careful consideration of the potential impacts and risks.

This thesis examined the potential to use the hydroponics nutrient film technique to grow commercially important crops using secondary-treated domestic wastewater. The crops chosen were a fruit crop (*Lycopersicon esculantum* - tomato), a leafy crop (*Beta vulgaris ssp. cicla* - silver beet) and a flower crop (*Dianthus caryophyllus* - carnation). Secondary-treated domestic wastewater was chosen because of the reduced risk of pathogen and heavy metal contamination in the crops and due to the guideline requirements for use of treated effluent for food crops. The possibility of using the effluent after the hydroponics treatment for further irrigation was also studied.

The ability of secondary-treated effluent to supply adequate nutrients to the crops was assessed relative to a commercially available hydroponics solution (Chapter 3). The amount of time the solution was left in the system (nutrient solution retention time) was dependant on the plant uptake of the solution. The results obtained showed that the nutrients in secondary treated effluent was adequate for the carnations, but not for

the food crops. The food crops from both treatments were compared to the produce purchased from a supermarket. The food crops showed signs of nutrient deficiency, particularly nitrogen.

Based on the findings of the first experiment, the nutrient solution retention time was amended to 14 days. The carnations were not tested with the shorter nutrient solution retention time (NSRT) because they performed well in the previous trial with the longer nutrient solution retention time. The edible food crops performed better and did not show signs of nutrient deficiency when the nutrient solution retention time was reduced to 14 days.

Further statistical analysis was conducted with the data from Chapters 3 and 4. Nutrient and water balances were calculated and the possible reason that the plants grown in the 14-day nutrient solution retention time took up more water, was a result of increased nutrients and better growth. A simple model was constructed to calculate height of the plants using multiple regression. The model was validated against the data collected from this study.

The experiment conducted in Chapter 6 determined the nutritional quality of the food crops. The harvests from the wastewater and commercially available hydroponics solution were compared to produce purchased from a supermarket and tested for total carotenoids, total soluble solids and ascorbic acid concentrations. The nutritional quality of the wastewater grown produce was comparable to those grown in the hydroponic solution and those purchased.

The risk of pathogen contamination to food crops and the die-off of pathogens in the hydroponic channels were studied in Chapter 7. This was tested by spiking the

commercial hydroponic medium with *Escherichia coli* and *Salmonella typhimurium* and monitoring bacterial pathogen die-off in the secondary treated domestic wastewater. The pathogen quality of the crop was tested in all treatments as well as on organically grown produce found at a local supermarket. The results of this experiment did not show any contamination on the surface of the food crops or within the food crops.

This study demonstrated that growing tomatoes, silver beet and carnations using secondary-treated domestic wastewater was successful when the nutrient solution retention time was adjusted to the optimum level. In arid, developing and remote communities, this system is ideal as it conserves and reuses water for commercially important crops without compromising the health of the environment or of human beings. It can also be implemented in urban areas, as the system can be scaled according to the availability of space. In addition to this, the effluent after going through this system can be used for open irrigation as it meets the World Health Organisation guidelines.

However, a number of additional concerns need further investigation. They include the transmission risk of other types of pathogen, which depends on the source of wastewater, and the effects of hormones and antibiotics on food crops and their effect on human health.



## ABBREVIATIONS

BOD	biological oxygen demand
CM	control medium (commercial hydroponics medium)
CMS	control medium spiked (commercial hydroponics medium spiked)
DO	dissolved oxygen
EC	electrical conductivity
ETC	Environmental Technology Centre
MAD	Maurice Alan Derrick
NATA	National Association of Testing Authorities
NFT	nutrient film technique
$\text{NH}_4^+\text{-N}$	ammonium-nitrogen
$\text{NO}_3^-\text{-N}$	nitrate-nitrogen
NSRT	nutrient solution retention time
O	organically grown produce
$\text{PO}_4^{3-}\text{-P}$	phosphate-phosphorus
se	standard error
TKN	total kheldjal nitrogen
TN	total nitrogen
TP	total phosphorus
TSS	total soluble solids
WC	water culture
WHO	World Health Organisation
WW	secondary-treated domestic wastewater

## TABLE OF CONTENTS

<b>DECLARATION</b>	<b>ii</b>
<b>LIST OF PUBLICATIONS</b>	<b>iii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iv</b>
<b>ABSTRACT</b>	<b>vi</b>
<b>ABBREVIATIONS</b>	<b>ix</b>
<b>TABLE OF CONTENTS</b>	<b>x</b>
<b>LIST OF FIGURES</b>	<b>xiii</b>
<b>LIST OF TABLES</b>	<b>xv</b>
<b>CHAPTER 1: INTRODUCTION</b>	<b>1</b>
1.1 <b>Need for reuse of treated wastewater</b>	<b>1</b>
1.2 <b>Concerns with wastewater reuse in horticulture</b>	<b>3</b>
1.3 <b>Wastewater reuse using the hydroponics system</b>	<b>4</b>
1.4 <b>Scope of this research</b>	<b>5</b>
<b>CHAPTER 2: LITERATURE REVIEW</b>	<b>8</b>
2.1 <b>Introduction</b>	<b>8</b>
2.2 <b>Water supply and sanitation</b>	<b>10</b>
2.3 <b>Wastewater and its reuse potential</b>	<b>12</b>
2.4 <b>Guidelines for reusing wastewater</b>	<b>14</b>
2.5 <b>Wastewater reuse in agriculture</b>	<b>16</b>
2.6 <b>Wastewater hydroponics</b>	<b>24</b>
2.7 <b>Conclusion</b>	<b>30</b>
<b>CHAPTER 3: NUTRIENT AVAILABILITY IN SECONDARY TREATED DOMESTIC               WASTEWATER FOR PLANT GROWTH</b>	<b>31</b>
3.1 <b>Introduction</b>	<b>31</b>
3.2 <b>Materials and methods</b>	<b>33</b>
3.3 <b>Results</b>	<b>37</b>
3.4 <b>Discussion</b>	<b>58</b>
3.5 <b>Conclusion</b>	<b>61</b>

<b>CHAPTER 4: EFFECT OF INCREASED NUTRIENT AVAILABILITY ON PLANT GROWTH</b>	<b>63</b>
4.1 Introduction	63
4.2 Materials and methods	64
4.3 Results	64
4.4 Discussion	78
4.5 Conclusion	85
<b>CHAPTER 5: MODELLING, WATER AND NUTRIENT BALANCES</b>	<b>86</b>
5.1 Introduction	86
5.2 Materials and methods	87
5.3 Results	88
5.4 Discussion	94
5.5 Conclusion	97
<b>CHAPTER 6: NUTRITIONAL QUALITY OF SILVER BEET AND TOMATOES GROWN IN SECONDARY TREATED WASTEWATER</b>	<b>98</b>
6.1 Introduction	98
6.2 Materials and methods	99
6.3 Results	99
6.4 Discussion	100
6.5 Conclusion	102
<b>CHAPTER 7: RISK OF PATHOGEN CONTAMINATION OF PLANTS IN WASTEWATER HYDROPONICS</b>	<b>103</b>
7.1 Introduction	103
7.2 Materials and methods	104
7.3 Results	107
7.4 Discussion	108
7.5 Conclusion	111
<b>CHAPTER 8: GENERAL DISCUSSION</b>	<b>112</b>
8.1 Introduction	112
8.2 Availability of nutrients for plant growth	113
8.3 Pathogen contamination of produce	114

<b>8.4</b>	<b>Nutritional quality of plants</b>	<b>115</b>
<b>8.5</b>	<b>Conclusion</b>	<b>116</b>
<b>CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH</b>		<b>117</b>
<b>CHAPTER 10: REFERENCES</b>		<b>118</b>

## LIST OF FIGURES

Figure 3.1: Greenhouse and hydroponics set-up	34
Figure 3.2: Experimental design	34
Figure 3.3: Growth of silver beet in WW and CM	37
Figure 3.4: Yellow silver beet leaves in WW	38
Figure 3.5: Height of silver beet grown in WW and CM	38
Figure 3.6: Purple and yellow tomato leaves grown in WW	39
Figure 3.7: Calcium deficiency in WW tomato	40
Figure 3.8: Tomatoes from WW and CM solution	40
Figure 3.9: Ripe tomatoes from WW and CM solution	41
Figure 3.10: Height of tomatoes grown in WW and CM	41
Figure 3.11: Carnations in WW and CM	42
Figure 3.12: Height of carnations grown in WW and CM	43
Figure 3.13: pH (a), EC (b) and DO (c) in silver beet channels	46
Figure 3.14: $\text{NO}_3^-$ -N (a), $\text{NH}_4^+$ -N (b) and $\text{PO}_4^{3-}$ -P (c) concentration in silver beet channels	47
Figure 3.15: pH (a), EC (b) and DO (c) in tomato channels	49
Figure 3.16: $\text{NO}_3^-$ -N (a), $\text{NH}_4^+$ -N (b) and $\text{PO}_4^{3-}$ -P (c) concentration in tomato channels	50
Figure 3.17: pH (a), EC (b) and DO (c) in carnation channels	53
Figure 3.18: $\text{NO}_3^-$ -N (a), $\text{NH}_4^+$ -N (b) and $\text{PO}_4^{3-}$ -P (c) concentration in carnation channels	54
Figure 4.1: Comparison of silver beet grown in different solutions	65
Figure 4.2: Quality of silver beet leaves in WW and CM	65
Figure 4.3: Quality of tomatoes grown in WW and CM	66
Figure 4.4: Growth of silver beet and tomatoes in WW and CM	66
Figure 4.5: pH (a), EC (b) and DO (c) in silver beet channels	69
Figure 4.6: TKN (a), $\text{NO}_3^-$ -N (b), $\text{NH}_4^+$ -N (c) concentration in silver beet channels	70
Figure 4.7: TP (a) and $\text{PO}_4^{3-}$ -P (b) concentration in silver beet channels	71
Figure 4.8: pH (a), EC (b) and DO (c) in tomato channels	73
Figure 4.9: TKN (a), $\text{NO}_3^-$ -N (b), $\text{NH}_4^+$ -N (c) concentration in tomato channels	74
Figure 4.10: TP (a) and $\text{PO}_4^{3-}$ -P (b) concentration in tomato channels	75
Figure 5.1: Predicted vs actual growth in silver beet (varied NSRT)	92
Figure 5.2: Predicted vs actual growth in tomatoes (varied NSRT)	92

Figure 5.3: Predicted vs actual growth in carnations (varied NSRT)	93
Figure 5.4: Predicted vs actual growth in silver beet (14-day NSRT)	93
Figure 5.5: Predicted vs actual growth in tomatoes (14-day NSRT)	94
Figure 7.1: Nutrient film technique experiment design	105
Figure 7.2: Water culture experiment design	105

## LIST OF TABLES

Table 2.1: Guidelines for wastewater reuse for food crops	15
Table 3.1: Number of fruits, average diameter and average weight of tomatoes	41
Table 3.2: Average number of carnations in WW and CM	43
Table 3.3: Initial concentration of nutrients in solutions	44
Table 3.4: ANOVA of CM and WW silver beet solutions	45
Table 3.5: ANOVA of CM and WW tomato solutions	51
Table 3.6: ANOVA of CM and WW carnation solutions	55
Table 3.7: Quality of effluent after hydroponics treatment	55
Table 3.8: Trace element concentration in silver beet leaves and tomato fruits	57
Table 3.9: Survival of carnations in a vase	57
Table 4.1: Number of buds, flowers and fruits in tomato plants	66
Table 4.2: Average diameter and weight of tomatoes	67
Table 4.3: Quality of effluent after hydroponics treatment	76
Table 4.4: ANOVA of CM and WW silver beet and tomato solutions	77
Table 4.5: Trace element concentration in silver beet and tomatoes	78
Table 5.1: Water balance	88
Table 5.2: Nutrient balance	89
Table 5.3: Nitrogen and phosphorus in edible parts of plants	89
Table 5.4: Correlation coefficients in varied NSRT	91
Table 5.5: Correlation coefficients in 14-day NSRT	91
Table 6.1: Nutritional quality of silver beet and tomatoes	100
Table 7.1: Pathogen reduction in NFT	107
Table 7.2: Pathogen reduction in WC	107
Table 7.3: Pathogen concentration in wash water	108