



**UNIVERSITI PUTRA MALAYSIA**

**NUTRIENT OPTIMIZATION AND COMPUTERIZED DECISION  
SUPPORT PROGRAM IN RECIRCULATING INTEGRATED  
AQUACULTURE SYSTEM**

**HAMID KHODA BAKHSH**

**FP 2005 35**



**NUTRIENT OPTIMIZATION AND COMPUTERIZED DECISION  
SUPPORT PROGRAM IN RECIRCULATING INTEGRATED  
AQUACULTURE SYSTEM**

**By**

**HAMID KHODA BAKHSH**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in  
Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**March 2005**



## **DEDICATION**

*To my dearest parents*

**&**

*Beloved wife*

**For their boundless support, true love, attention and encouragement**



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

**NUTRIENT OPTIMIZATION AND COMPUTERIZED DECISION  
SUPPORT PROGRAM IN RECIRCULATING INTEGRATED  
AQUACULTURE SYSTEM**

By

**HAMID KHODA BAKHSH**

**March 2005**

**Chairman : Professor Abdul Razak Alimon, PhD**

**Faculty : Agriculture**

There are many research activities to improve sustainable aquaculture and agriculture production in the wide world. Sustainable aquaculture is referred to as production of aquatic commodities through farming activities with social, economic and environmental sustainability.

A series of experiments were conducted to compare different inorganic and organic fertilizers to improve production of *Macrobrachium rosenbergii* and to make a decision support program in an artificial sustainable aquaculture-agriculture system. Simply, nutrient wastes from culture tanks were used to fertilize hydroponics or terrestrial plants production via irrigation water. The sustainability and success functioning of the whole system were involved to manage and optimize the use of supplemented minerals, diet and desirable environment for each compartment (prawn, plant and microorganisms).



The first experiment was made to evaluate the tolerance of *M. rosenbergii* in different levels of inorganic fertilizer (EC) formulated in nutrient film technique (NFT) vegetable production system. Results of the first experiment indicated that desirable growth rate of *M. rosenbergii* was obtained using 0.1 to 0.5EC of supplemental liquid fertilizer. High concentration of potassium (117-177 mg l<sup>-1</sup>), ammonia (0.72-1.05 mg l<sup>-1</sup>) and copper (0.04-0.06 mg l<sup>-1</sup>) inhibited the growth rate of *M. rosenbergii* in integrated culture system.

The second experiment was carried out to assess the effects of different nutrient and stocking density on different population of *M. rosenbergii* in polyculture system. A different range of inorganic and organic fertilizer was used in the polyculture of plant and freshwater prawn species. Overall results indicated that essential concentration of nutrients, source and *M. rosenbergii* stocking density have played a major role in the effectiveness of suitable range of minerals in integrated production system. The results also demonstrated that 0.5 EC liquid inorganic fertilizer was not suitable to provide optimum nutrients and chicken manure is still an important fertilizer even in indoor integrated culture system.

Finally, a comparative study was conducted to evaluate the optimum level of chicken manure and formulated inorganic nutrients in an artificial integrated culture system. The results indicated that high density culture of *M. rosenbergii* juveniles (380-400 individual m<sup>-2</sup>) in fiberglass tanks is possible by the installation of artificial substrate and controlling of nutrient concentration in system. Moreover the addition of aeration tank significantly improved the quality of water (DO and pH) and freshwater prawn growth

(1343.0 g/tank) in recirculated polyculture system. The application of  $70 \text{ g m}^{-3}$  chicken manure alone encouraged growth of benthic and periphyton algae in culture tanks. The overall observation illustrated the desirable combination of supplemental liquid fertilizer and chicken manure is essential to obtain best growth for each compartment in sustainable polyculture system.

A visual expert program (IAAS) was adopted to improve managing and develop technical operation in an artificial integrated culture system. The operation of the polyculture system required the specific knowledge, developing and application of computer systems to excellent operation, control of water quality variables, dissolved nutrients and feed to avoid the production of toxic substance and increase self efficiency and sustainability of the culture system. The accuracy of IAAS expert program was evaluated by polynomial and linear regression techniques through additional experiment. The comparison of results (yield and survival) in expert and real culture system represents higher variation of survival, prawn and plant yields in abnormal culture system. Moreover the evaluation processes demonstrated succeed performance of IAAS expert program in prediction results of optimized integrated culture system (with low variation). In aquaculture, the success estimation of production depends largely on the state of physical and chemical parameters which define optimal culture conditions.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PENGOPTIMUMAN NUTRIEN DAN PROGRAM SOKONGAN KEPUTUSAN BERKOMPUTER DALAM SISTEM INTEGRASI AKUAKULTUR KITAR SEMULA**

Oleh

**HAMID KHODA BAKHSH**

**Mac 2005**

**Pengerusi : Profesor Abdul Razak Alimon, PhD**

**Fakulti : Pertanian**

Banyak aktiviti kajian telah dijalankan untuk meningkatkan pengeluaran akuakultur dan pertanian yang daya tahan di serata dunia. Daya tahan akuakultur dirujuk sebagai pengeluaran komoditi akuatik melalui aktiviti pengkulturan dengan sosial, ekonomi dan daya tahan persekitaran.

Satu siri eksperimen telah dijalankan untuk membandingkan perbezaan baja organic dan bukan organic untuk meningkatkan pengeluaran *Macrobrachium rosenbergii* dan menghasilkan satu program sokongan keputusan dalam sistem artifisial akuakultur – pertanian yang berdaya tahan. Iaitu, nutrien bahan buangan dari tangki kultur digunakan untuk menyuburkan hidroponik atau pengeluaran tanaman terestial melalui saluran air. Daya bertahan dan kejayaan fungsi keseluruhan sistem yang terlibat adalah untuk mengurus dan mengoptimakan kegunaan mineral tambahan, diet dan keadaan



persekitaran yang sesuai untuk setiap satu bahagian (udang, tanaman dan mikroorganisma).

Eksprimen pertama dihasilkan untuk menilai daya ketahanan *M. rosenbergii* untuk kepekatan baja bukan organik (EC) yang berbeza diformulasi dalam teknik filem nutrien (NFT) sistem pengeluaran sayuran. Keputusan kajian ini menunjukkan bahawa kadar pertumbuhan yang diperlukan untuk *M. rosenbergii* diperolehi dengan menggunakan 0.1 hingga 0.5 EC baja tambahan dalam bentuk cecair. Kepekatan potassium yang tinggi ( $117-177 \text{ mg l}^{-1}$ ), amonia ( $0.72-1.05 \text{ mg l}^{-1}$ ) dan tembaga ( $0.04-0.06 \text{ mg l}^{-1}$ ) menghalang kadar tumbesaran *M. rosenbergii* di dalam sistem kultur intergrasi.

Eksperimen kedua telah dijalankan untuk menilai kesan nutrien dan densiti stok yang berbeza ke atas populasi *M. rosenbergii* yang berlainan di dalam sistem polikultur. Satu julat baja organik dan bukan organik digunakan di dalam polikultur tanaman dan spesies udang airtawar. Keseluruhan keputusan menunjukkan bahawa kepekatan nutrien yang perlu, sumber dan kadar densiti untuk *M. rosenbergii* memainkan peranan utama di dalam keberkesanan julat mineral yang sesuai untuk sistem pengeluaran intergrasi. Keputusan turut menunjukkan bahawa baja cecair bukan organik 0.5 EC adalah tidak sesuai sebagai penyumbang nutrien optima dan najis ayam masih satu baja yang penting walaupun untuk sistem kultur intergrasi secara tertutup.

Kajian perbandingan dijalankan untuk menilai takat optima najis ayam dan formulasi nutrien bukan organik dalam sistem polikultur intergrasi artificial. Keputusan



menunjukkan bahawa kultur *M. rosenbergii* juvenile dengan densiti tinggi (380-400 individual  $m^{-2}$ ) dalam tangki gentian kaca boleh dijalankan dengan pemasangan substrat artificial dan mengawal kepekatan nutrient di dalam sistem. Lebih lagi dengan penambahan tangki pengudaraan jelasnya akan meningkatkan kualiti air (DO and pH) dan tumbesaran udang air tawar (1343.0 g/tangki) di dalam sistem kultur intergrasi kitar-semula. Penggunaan najis ayam yang lebih tinggi ( $70g m^{-3}$ ) akan menggalakkan tumbesaran alga benthik dan periphyton di dalam tangki kultur.

Keseluruhan pemerhatian menggambarkan kombinasi baja cecair tambahan dan najis ayam adalah perlu untuk mendapatkan tumbesaran terbaik untuk tiap satu kompartmen di dalam sistem polikultur berdaya-tahan.

Satu program visual pakar (IAAS) telah digunakan untuk memperbaiki pengurusan dan membentuk operasi teknikal di dalam sistem kultur intergrasi artifisial. Operasi sistem polikultur memerlukan pengetahuan yang spesifik, membentuk dan mengaplikasikan penggunaan sistem komputer untuk operasi yang terbaik, mengawal pembolehubah kualiti air, nutrien terlarut dan makanan untuk mengelakkan penghasilan bahan toksik, meningkatkan kecekapan diri dan daya-tahan sistem kultur tersebut. Ketepatan program pakar IAAS telah diuji dengan teknik polynomial dan regresi linear melalui eksperimen tambahan. Perbandingan keputusan (hasil dan kemandirian) untuk sistem pakar dan kultur sebenar menunjukkan variasi yang tinggi dalam kemandirian, udang, dan hasil tanaman dalam sistem kultur abnormal. Lebih lagi kerana proses penilaian menunjukkan kejayaan dalam persembahan program pakar IAAS dalam menjangka keputusan untuk sistem kultur intergrasi yang optima (dengan variasi rendah). Di dalam akuakultur,

kejayaan dalam menjangka pengeluaran banyak bergantung kepada keadaan parameter fizikal dan kimia yang mentafsirkan keadaan kultur yang optima.



## ACKNOWLEDGEMENTS

In the name of Greatest Merciful and Compassionate, to him do I entrust myself; to him be praise and grace, and with him is success, immunity and comfort.

I would like to express my sincere and grateful thanks to my supervisory committee chairman, Prof. Dr. Abdul Razak Alimon, Prof. Dr. Mohd. Khanif Yusop, Dr. Annie Christianus and Assoc. Prof. Dr. Abdul Rashid Mohamed Shariff for their active and passive contribution during this study.

I gratefully acknowledge Mr. Aizam Zainal Abidin for his guidance, encouragement and supports in this study. My special thanks and appreciation to my lecturers in the Faculty of Engineering (Dr. Vijayaraghavan, Pn. Wan Azizun), Faculty of Veterinary Medicine (Assoc. Prof. Dr. Hassan, Prof. Dr. Shariff) and all former lecturers for their efforts and contribution towards the expansion of basic knowledge and completion this study.

My deep appreciations to the staffs of Agricultural Technology, Animal Science and Land Management Departments as well as Hatchery for their help and facilities throughout the course of the study (Assoc. Prof. Dr. Mihdzar, Assoc. Prof. Dr. Salleh, Muhammad Abdullah, Jasni M. Yusoff, En. Ibrahim, Jamil, Pn. Mere, Zetty and Liza).

I would like to acknowledge all lab assistants and friends for their technical and professional guidance to improve my study. I deeply appreciate my mother, who always supportive and strongly encourage me to believe in goodness, brightness and humanity.



I certify that an Examination Committee met on 18 March 2005 to conduct the final examination of Hamid Khoda Bakhsh on his Doctor of Philosophy thesis entitled “Nutrient Optimization and Computerized Decision Support Program in Recirculating Integrated Aquaculture System” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

**DAHLAN ISMAIL, PhD**

Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Chairman)

**CHE ROOS SAAD, PhD**

Assoc. Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

**MOHD RAZI ISMAIL, PhD**

Assoc. Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

**ROSHADA HASHIM, PhD**

Professor  
Faculty of Biological Science  
Universiti Sains Malaysia  
(Independent Examiner)

---

**GULAM RUSUL RAHMAT ALI, PhD**

Professor/Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:



This thesis submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfilment for the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

**ABDUL RAZAK ALIMON, PhD**

Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Chairman)

**MOHD. KHANIF YUSOP, PhD**

Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

**ABDUL RASHID MOHAMED SHARIFF, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**ANNIE CHRISTIANUS, PhD**

Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

---

**AINI IDERIS, PhD**

Professor/Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:



## **DECLARATION**

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

---

**HAMID KHODA BAKHSH**

Date:



## TABLE OF CONTENTS

|   | <b>Page</b> |
|---|-------------|
| <b>DEDICATION</b>   | ii          |
| <b>ABSTRACT</b>   | iii         |
| <b>ABSTRAK</b>  | vi          |
| <b>ACKNOWLEDGEMENTS</b>   | x           |
| <b>APPROVAL</b>   | xi          |
| <b>DECLARATION</b>  | xiii        |
| <b>LIST OF TABLES</b>   | xviii       |
| <b>LIST OF FIGURES</b>  | xxii        |
| <b>LIST OF ABBREVIATIONS</b>                                    | xxv         |
| <br>  |             |
| <b>CHAPTER</b>  |             |
| <br>  |             |
| <b>I INTRODUCTION</b>   | <b>1</b>    |
| Statement of the Problem  | 2           |
| The Significance of Study                                       | 4           |
| Objectives  | 6           |
| <br>  |             |
| <b>II LITERATURE REVIEW</b>                                     | <b>8</b>    |
| Aquaculture and Water Quality                                   | 8           |
| Dissolved Oxygen (DO)   | 9           |
| Temperature   | 10          |
| pH  | 11          |
| Ammonia (NH <sub>3</sub> )                                      | 12          |
| Biological Oxygen Demand – BOD                                  | 13          |
| Aquaculture and Integrated Fish Farming                         | 15          |
| Integrated Fish Farming   | 15          |
| Integrated Agriculture–Aquaculture                              | 17          |
| Economics and Environment in the Integration Culture<br>Systems | 20          |
| Polyculture of <i>Macrobrachium rosenbergii</i>                 | 21          |
| Recirculation System in Aquaculture                             | 24          |
| Water Recirculation and Filters in Aquaculture                  | 25          |
| Environment and Organic Waste Recycling                         | 27          |
| Vegetable Hydroponics Production                                | 28          |
| NFT Hydroponics System and Nutrients                            | 29          |
| Electrical Conductivity (EC)                                    | 32          |
| Aquaponics and Nutrient Film Technique System                   | 34          |
| Plant and Nutrient Deficiency                                   | 36          |
| Nutrient and Fertilizer in Aquatic Ecosystem                    | 38          |
| Computer and Decision Support Software in Aquaculture           | 42          |



|            |  |    |
|------------|--|----|
| <b>III</b> | <b>GENERAL METHODOLOGY</b>   | 45 |
|            | Hydroponics System   | 45 |
|            | Water Quality Management (Evaluation and Methods)  | 48 |
|            | Biological Oxygen Demand (BOD <sub>5</sub> ) Test  | 49 |
|            | Result Evaluation  | 49 |
|            | Preparation of Nutrient Solution   | 50 |
|            | Sample (Collection and Preparation)  | 52 |
|            | Plant Growth Analysis  | 53 |
|            | Statistical Analysis   | 53 |
| <b>IV</b>  | <b>FRESHWATER PRAWN (<i>MACROBRACHIUM ROSENBERGII</i>) PRODUCTION IN AN INTEGRATED HYDROPONICS NUTRIENT FILM TECHNIQUE SYSTEM (NFT)</b>  | 54 |
|            | Introduction   | 54 |
|            | Materials and Methods  | 55 |
|            | Integrated Culture System  | 55 |
|            | Results  | 57 |
|            | Water Quality Variables  | 57 |
|            | Nutrient   | 58 |
|            | Relationships of Nutrients and Electrical Conductivity (EC)  | 58 |
|            | Plant Growth   | 62 |
|            | <i>M. rosenbergii</i> and Growth Rate  | 64 |
|            | Discussion   | 65 |
|            | Nutrient, Freshwater prawn and plant   | 65 |
|            | Nitrogen (Nitrate)   | 66 |
|            | Ammonia  | 67 |
|            | Phosphorus (P)   | 69 |
|            | Potassium (K)  | 70 |
|            | Iron (Fe)  | 71 |
|            | Copper (Cu) and Other Elements   | 71 |
|            | Conclusion   | 75 |
| <b>V</b>   | <b>EFFECTS OF DIFFERENT TYPES OF NUTRIENT AND STOCKING DENSITIES ON PRODUCTION OF FRESHWATER PRAWN (<i>MACROBRACHIUM ROSENBERGII</i>) IN A RECIRCULATING INTEGRATED AQUACULTURE-AGRICULTURE SYSTEM</b> | 77 |
|            | Introduction   | 77 |
|            | Materials and Methods  | 78 |
|            | Results  | 80 |
|            | Water Quality Variables  | 80 |
|            | Electrical Conductivity (EC)   | 80 |
|            | Plant Growth   | 81 |
|            | Prawn Growth Rate  | 82 |
|            | Nutrient and Polyculture System  | 84 |
|            | Discussion   | 88 |





|            |   |     |
|------------|---|-----|
|            | Water Quality   | 88  |
|            | Prawn Growth  | 90  |
|            | Stocking Density of <i>M. rosenbergii</i>   | 91  |
|            | Nutrient Dynamics in Polyculture System   | 92  |
|            | Conclusion  | 97  |
| <b>VI</b>  | <b>OPTIMIZATION IN A PROTOTYPE POLY CULTURE SYSTEM OF FRESHWATER PRAWN AND VEGETABLE WITH DIFFERENT LEVELS OF POULTRY MANURE AND TRACE ELEMENTS</b> | 98  |
|            | Introduction  | 98  |
|            | Materials and Methods   | 99  |
|            | Results   | 101 |
|            | Water Quality Variables   | 101 |
|            | Plant Growth  | 104 |
|            | Prawn Growth  | 105 |
|            | Biological Oxygen Demand (BOD <sub>5</sub> )  | 106 |
|            | Chlorophyll <i>a</i> and N:P Ratio  | 106 |
|            | Nutrients in Integrated Culture System  | 107 |
|            | Nitrogen (N)  | 111 |
|            | Phosphorus (P)  | 112 |
|            | Potassium (K)   | 112 |
|            | Magnesium (Mg)  | 113 |
|            | Iron (Fe)   | 113 |
|            | Zinc (Zn)   | 114 |
|            | Manganese (Mn)  | 115 |
|            | Copper (Cu)   | 115 |
|            | Calcium (Ca)  | 116 |
|            | Discussion  | 121 |
|            | Water Quality   | 121 |
|            | Growth Parameters   | 124 |
|            | Biological Oxygen Demand (BOD <sub>5</sub> )  | 128 |
|            | Primary Production and N:P Ratio  | 129 |
|            | Nutrient Dynamic in Integrated Culture System   | 130 |
|            | Conclusion  | 136 |
| <b>VII</b> | <b>DECISION SUPPORT PROGRAM AND COMPUTERIZING VISUAL ASSESSMENT IN SUSTAINABLE INTEGRATED AGRICULTURE AND AQUACULTURE SYSTEM (IAAS)</b>             | 137 |
|            | Introduction  | 137 |
|            | Methods and Design Rationale  | 138 |
|            | Results and Discussion  | 144 |
|            | Sustainable Aquaculture Purpose   | 144 |
|            | Volume of Aeration Tank (m <sup>3</sup> )   | 150 |
|            | Hydraulic Retention Time (HRT/hours) for RBC  | 151 |
|            | Summary   | 153 |



|             |   |     |
|-------------|---|-----|
|             | Conclusion  | 154 |
| <b>VIII</b> | <b>PREDICTION AND VALIDATION PROCESSES OF<br/>COMPUTERIZED VISUAL ASSESSMENT IN AN<br/>ARTIFICIAL INTEGRATED AGRICULTURE AND<br/>AQUACULTURE SYSTEM</b> | 155 |
|             | Introduction  | 155 |
|             | Methods and Design Rationale  | 156 |
|             | Water Quality and Bioassay Data   | 159 |
|             | Validation Processes  | 162 |
|             | Results and Discussion  | 167 |
|             | Summary   | 170 |
|             | Conclusion  | 172 |
| <b>IX</b>   | <b>GENERAL DISCUSSION</b>   | 173 |
|             | Growth Rate   | 174 |
|             | Nutrient Optimization and Sustainable Aquaculture   | 179 |
|             | Computerized Decision Support System  | 186 |
|             | Conclusions   | 188 |
|             | Recommendation  | 189 |
|             | <b>BIBLIOGRAPHY</b>   | 190 |
|             | <b>APPENDICES</b>   | 210 |
|             | <b>BIODATA OF THE AUTHOR</b>  | 253 |
|             | Publications in the Conference and Seminars   | 254 |



## LIST OF TABLES

| Table |   | Page |
|-------|---|------|
| 1     | Aquaculture production by species groups in different ecosystem of the world  | 2    |
| 2     | The biological oxygen demand (24 h) for various inputs into pond fish culture   | 14   |
| 3     | Theoretically ideal concentration of essential nutrients in NFT hydroponics system  | 32   |
| 4     | EC-values of nutrient solution for different plant and light condition in the root environment  | 34   |
| 5     | Ratio of macro and micronutrient in recirculating aquaculture-agriculture system (fish and vegetable hydroponics)                                       | 35   |
| 6     | Typical composition of organic fertilizer materials as dry weight basis   | 42   |
| 7     | The physical and chemical characteristics of artificial shrimp and prawn feed   | 47   |
| 8     | Mean of nutrients (mg) in artificial prawn diet and chicken manure (CM) used for integrated culture system  | 47   |
| 9     | Water quality equipments used in integrated culture system  | 49   |
| 10a   | Weight (g) of pure substances to be dissolved in 1000 and 500 liters of water to give ideal concentration (Cooper's formula) in two different solutions | 51   |
| 10b   | Weight (g) of pure substances to be dissolved in 1000 and 500 liters of water to give ideal concentration (Cooper's formula) in two different solutions | 52   |
| 11    | The summary of first experiment includes different stock density, size and feed requirements in recirculatory polyculture system                        | 56   |
| 12    | Range of chemical and physical variables in integrated culture tanks during 35 days of production cycle (mean $\pm$ se)                                 | 57   |



|    |   |     |
|----|---|-----|
| 13 | Concentration of nutrients ( $\text{mg l}^{-1}$ ) in polyculture system during the production cycle (mean $\pm$ se)   | 59  |
| 14 | Wet and dry weight of leaf, root (WWL, DWL, WWR and DWR) and leaves area (LA) of Chinese cabbage at the end of polyculture system (mean $\pm$ se)                 | 63  |
| 15 | Wet and dry weight of leaf, root (WWL, DWL, WWR and DWR) and leaves area (LA) of lettuce at the end of polyculture system (mean $\pm$ se)                         | 63  |
| 16 | Mean body weight (g) of freshwater prawn ( <i>M. rosenbergii</i> ) during 35 days production cycle (mean $\pm$ se)  | 64  |
| 17 | Mean body length (cm) of freshwater prawn ( <i>M. rosenbergii</i> ) during 35 days production cycle (mean $\pm$ se)   | 64  |
| 18 | Tolerance of <i>M. rosenbergii</i> to different chemical substances   | 76  |
| 19 | The summary of second experiment includes different fertilizer, size and feed requirements in recirculated polyculture system                                     | 79  |
| 20 | Survivals (%), specific growth rate (SGR), average daily growth (ADG), net yield and feed conversion ratio (FCR) of <i>M. rosenbergii</i> culture (mean $\pm$ se) | 83  |
| 21 | Concentration of nutrients ( $\text{mg l}^{-1}$ ) in rearing tanks during production cycle (mean $\pm$ se)  | 85  |
| 22 | Nutrient content in lettuce, Chinese cabbage, sediment and prawn tissues in integrated culture system ( $\text{mg g}^{-1}$ )                                      | 87  |
| 23 | Minerals content in lettuce, Chinese cabbage and spinach  | 94  |
| 24 | Effect of stocking density of <i>M. rosenbergii</i> on nutrient concentration (%) in same treatments  | 95  |
| 25 | The summary of third experiment includes different rate of chicken manure and inorganic fertilizer (microelements) and feed requirements in mix-culture system    | 100 |
| 26 | Recommended nutrient (stock) solution for plant and freshwater prawn culture  | 101 |

|    |  |     |
|----|--|-----|
| 27 | Mean ( $\pm$ SE) temperature ( $T^{\circ}\text{C}$ ), dissolved oxygen (DO), specific conductivity (SPC), salinity (Sal), turbidity (Tur), pH, total dissolved solid (TDS) and ammonia ( $\text{NH}_3$ ) concentration of different treatments in polyculture system | 102 |
| 28 | Range of temperature ( $T^{\circ}\text{C}$ ), dissolved oxygen (DO), specific conductivity (SPC), salinity (Sal), turbidity (Tur), pH, total dissolved solid (TDS) and ammonia ( $\text{NH}_3$ ) concentration during culture period                                 | 103 |
| 29 | Weight and total yield of lettuce at harvest in the integrated culture system (mean $\pm$ se)  | 104 |
| 30 | Survivals (%), specific growth rate (SGR), average daily growth (ADG), net yield and feed conversion ratio (FCR) of <i>M. rosenbergii</i> in polyculture system and natural pond (mean $\pm$ se)   | 105 |
| 31 | Evaluation of nutrient concentration ( $\text{mg l}^{-1}$ ) in water of <i>M. rosenbergii</i> culture tanks (mean $\pm$ se)  | 108 |
| 32 | Weekly changes of nutrients in recirculated polyculture system ( $\text{mg l}^{-1}$ )  | 109 |
| 33 | Trend, regression equation and maximum value of nitrogen (N) in different treatments   | 111 |
| 34 | Recovery of nutrients in plant, root, sediment and prawn tissue as percent (%) of <i>M. rosenbergii</i> diet, CM and supplemental liquid fertilizer  | 118 |
| 35 | Recovery of nutrients ( $\text{g tank}^{-1}$ ) in different compartments of recirculated polyculture system (mean $\pm$ se)  | 119 |
| 36 | Total and specific rate of nutrients recovery ( $\text{g tank}^{-1}$ ) in plant, root, sediment, prawn tissue and soluble minerals (feed, chicken manure and liquid fertilizer) in integrated culture system   | 120 |
| 37 | Different supplemented liquid fertilizer, chicken manure and density culture of <i>M. rosenbergii</i> in 4 <sup>th</sup> integrated culture experiment   | 160 |
| 38 | Water quality in the <i>M. rosenbergii</i> rearing tanks of integrated culture system (mean $\pm$ se)  | 161 |
| 39 | Plant and prawn yield, survivals (%), average daily growth (ADG) and feed conversion ratio (FCR) of <i>M. rosenbergii</i> at harvest in the integrated culture system (mean $\pm$ se)  | 162 |

|    |  |     |
|----|--|-----|
| 40 | Comparison of the selected variables in the real experiment and IAAS expert program  | 164 |
| 41 | Comparison on the survivals (%), specific growth rate (SGR), average daily growth (ADG), net yield and feed conversion ratio (FCR) of <i>M. rosenbergii</i> and plant in all polyculture systems | 178 |
| 42 | Some researches on <i>M. rosenbergii</i> culture with different growth rate variables  | 178 |
| 43 | Comparative nutrients content in the water of culture tanks of all polyculture experiments   | 184 |
| 44 | Ideal and optimized concentration of essential nutrients in NFT hydroponics and integrated culture systems   | 184 |
| 45 | Comparison of nutrient recovery (ratio) in plant, root, sediment and prawn tissue (mg)   | 185 |



## LIST OF FIGURES

| Figures |  | Page |
|---------|--|------|
| 1       | A perspective model of sustainable integrated agriculture-aquaculture of freshwater prawn, vegetable and poultry   | 19   |
| 2       | The basic perspective of a hydroponics plant production system (NFT)   | 31   |
| 3       | Monitoring and result prediction of a sustainable integrated agriculture-aquaculture system (General model)  | 44   |
| 4       | Primary and developed models of integrated culture system  | 46   |
| 5       | Quadratic relationships between supplemental nutrients include nitrogen, ammonia, phosphorus and potassium with different electrical conductivity (EC) in treatments   | 60   |
| 6       | Quadratic relationships between iron (Fe), copper (Cu), magnesium (Mg) and calcium (Ca) with different electrical conductivity (EC) in treatments                      | 61   |
| 7       | Total yields (green leaves) of Chinese cabbage and lettuce after five weeks production cycle. Plants with a same letter are not significantly different                | 63   |
| 8       | Changes of ammonia concentration and <i>M. rosenbergii</i> survival in different culture tanks   | 68   |
| 9       | Changes of copper (Cu) concentration and survival of <i>M. rosenbergii</i> in different treatments   | 72   |
| 10      | Relationship of electrical conductivity and time (linear regression) in integrated culture system  | 81   |
| 11      | Total yields of lettuce and Chinese cabbage at harvest in polyculture trial. Means within a row followed by a same letter are not significantly different ( $P>0.05$ ) | 82   |
| 12      | Polynomial and linear regression of freshwater prawn (wet weight) in polyculture system  | 83   |
| 13      | Cycle and evaluation process of nutrients recovery in an artificial integrated culture system  | 86   |



|    |  |     |
|----|--|-----|
| 14 | Percentage of nutrient concentration compares to 0.5H media (100) in different polyculture tanks                             | 94  |
| 15 | Changes of ammonia concentration in the current polyculture system   | 103 |
| 16 | Linear relationship between BOD <sub>5</sub> and all fertilized treatments of integrated culture system (CM= chicken manure) | 106 |
| 17 | Concentration of chlorophyll <i>a</i> (benthic algae) and N: P ratio in <i>M. rosenbergii</i> culture tanks                  | 107 |
| 18 | Polynomial regression of nutrient concentration in the integrated culture system   | 110 |
| 19 | Fluctuation of turbidity (NTU), nitrate and ammonia (mg l <sup>-1</sup> ) concentrations in freshwater (FW) culture tanks    | 127 |
| 20 | Computerize evaluation of sustainable integrated agriculture-aquaculture of freshwater prawn, plants and poultry manure      | 140 |
| 21 | Basic steps in structure and building of an expert system  | 141 |
| 22 | Conceptual processes and assessment of IAAS expert programs  | 143 |
| 23 | Visual IAAS expert program consist of different components and sub-interface   | 144 |
| 24 | Visual interface and general information of sustainable aquaculture-agriculture systems                                      | 145 |
| 25 | Visual interface of statistical integrated fish farming (estimation and prediction of yield)                                 | 146 |
| 26 | Statistical visual model of growth rate parameters in integrated culture system  | 147 |
| 27 | Visual and statistical form of water quality variables with nutrient evaluation  | 149 |
| 28 | Visual interface and statistical methods for wastewater managements  | 152 |
| 29 | Diagram presenting parameters, components and processing of compliance auditing system (IAAS)                                | 158 |





|    |   |     |
|----|---|-----|
| 30 | Graphical visual interface showing the compliance audit for evaluating of <i>M. rosenbergii</i> survival and yield (first and second step)        | 163 |
| 31 | Graphical visual interface showing the compliance audit for prediction of <i>M. rosenbergii</i> yield with optimum levels of individual component | 163 |
| 32 | Linear relationships of survival, prawn and plant yields between IAAS program and artificial polyculture trial                                    | 165 |
| 33 | Quadratic and linear regression trend of selected variables between IAAS expert program and artificial polyculture trial                          | 166 |
| 34 | Schematic structure showing the steps development of integrated culture and computerized expert system  | 187 |

