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APPENDICES

Appendix A

Standard Curve for Ammonia, Nitrite, and Nitrate

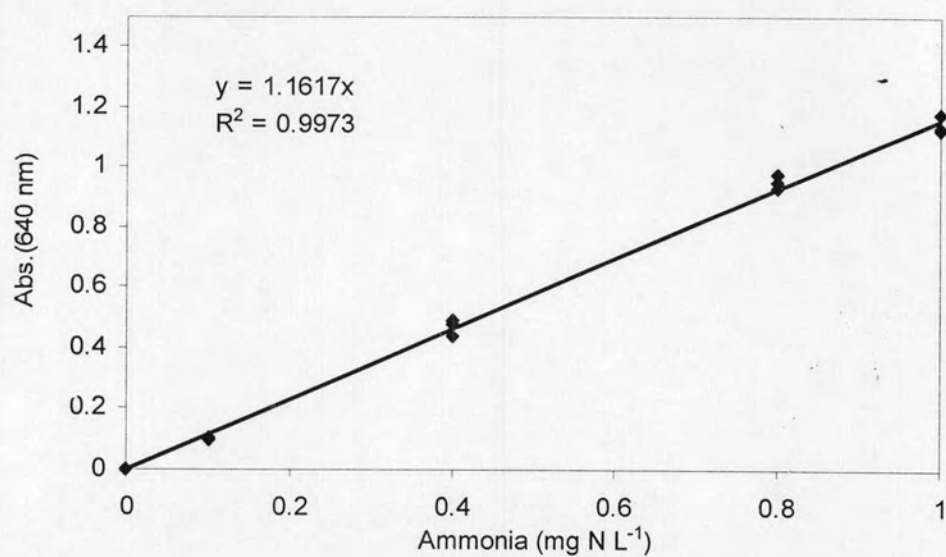


Figure A-1 Standard curve for ammonia (NH₄⁺-N).

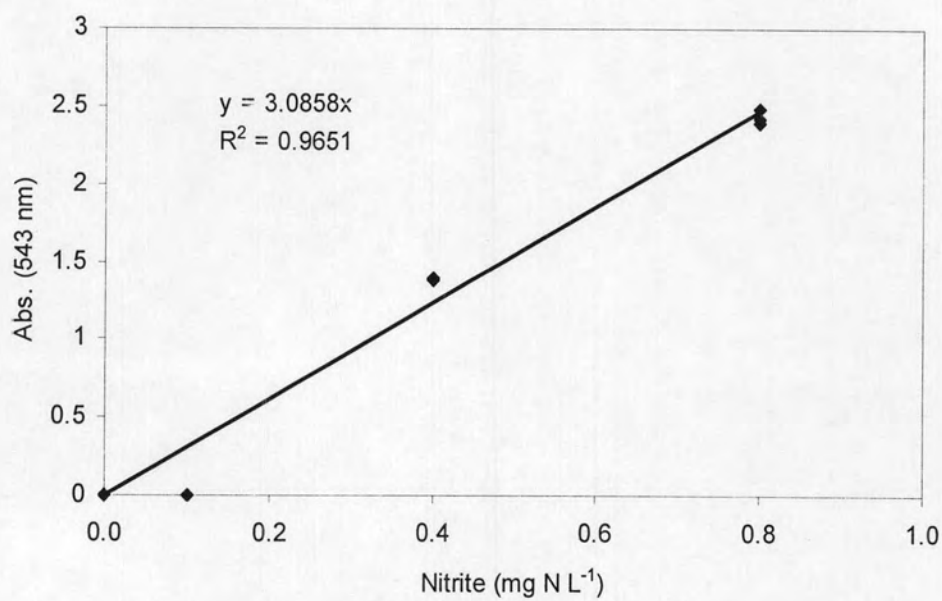


Figure A-2 Standard curve for nitrite (NO₂⁻-N).

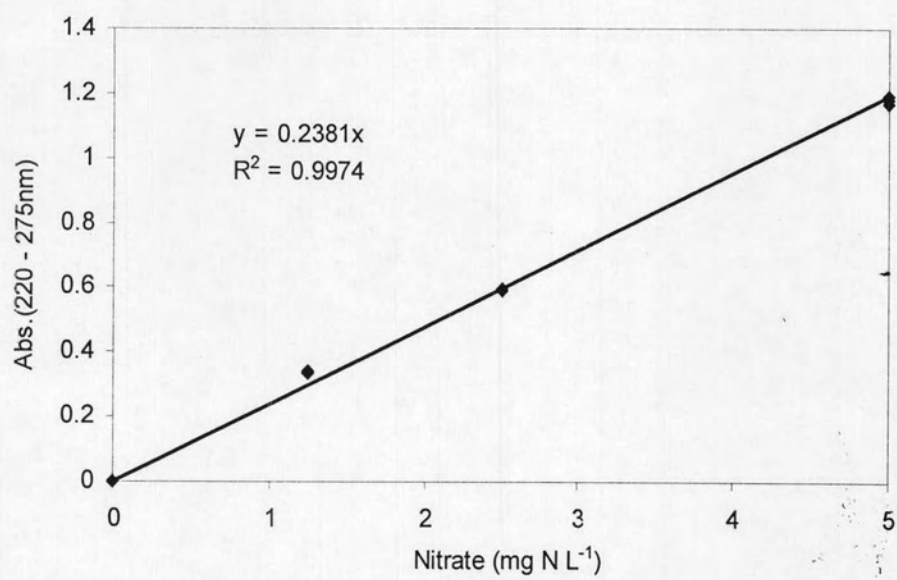


Figure A-3 Standard curve of nitrate (NO₃⁻-N).

Appendix B

Information of the Proposed Aquaculture Systems

Table B-1 Concentrations of ammonia, nitrite, and nitrate in T1 with the initial stocking density of 0.7 kg m^{-3} .

Day	Ammonia (mg N L^{-1})		Nitrite (mg N L^{-1})		Nitrate (mg N L^{-1})	
	Average	SD	Average	SD	Average	SD
3	0.38	0.03	0.00	0.00	0.99	0.00
5	0.63	0.05	0.12	0.12	1.00	0.00
7	1.28	0.05	0.19	0.01	2.79	0.01
9	0.71	0.06	0.43	0.10	2.73	0.01
11	0.46	0.03	0.58	0.13	3.22	0.00
13	0.48	0.04	0.09	0.02	4.64	0.00
15	0.48	0.01	0.21	0.03	5.85	0.02
17	0.39	0.01	0.04	0.02	4.05	0.00
18	0.37	0.08	0.19	0.07	4.18	0.01
21	0.84	0.03	0.26	0.02	8.47	0.00
24	0.10	0.01	0.37	0.01	4.18	0.00
26	0.16	0.03	0.03	0.02	12.29	0.00
29	0.05	0.01	0.29	0.02	17.46	0.01
31	0.14	0.01	0.02	0.01	16.36	0.02
33	0.03	0.01	0.21	0.03	14.12	0.01
35	0.09	0.01	0.00	0.00	16.02	0.00
36	0.09	0.00	0.49	0.04	23.07	0.00
38	0.16	0.01	0.33	0.03	9.07	0.00
39	0.10	0.00	0.36	0.00	19.69	0.00
40	0.10	0.00	0.28	0.00	24.62	0.00
41	0.15	0.00	0.67	0.07	32.48	0.01
42	0.10	0.00	0.69	0.06	31.55	0.00
43	0.11	0.00	0.70	0.01	35.71	0.00
44	0.13	0.01	0.71	0.02	36.95	0.00

Table B-2 Concentrations of ammonia, nitrite, and nitrate in T2 with the initial stocking density of 0.7 kg m^{-3} .

Day	Ammonia (mg N L^{-1})		Nitrite (mg N L^{-1})		Nitrate (mg N L^{-1})	
	Average	SD	Average	SD	Average	SD
3	0.32	0.04	0.02	0.06	0.51	0.00
5	0.72	0.04	0.11	0.21	0.73	0.01
7	0.25	0.04	0.17	0.01	2.13	0.00
9	1.34	0.14	0.24	0.03	2.40	0.01
11	1.00	0.04	0.16	0.04	2.45	0.01
13	1.24	0.14	0.16	0.06	4.12	0.01
15	1.53	0.14	0.28	0.04	5.34	0.00
17	1.90	0.16	0.08	0.03	3.37	0.00
18	0.94	0.12	1.54	0.04	8.51	0.00
21	2.34	0.25	0.50	0.01	5.71	0.01
24	0.20	0.02	0.75	0.02	11.73	0.00
26	0.08	0.03	0.39	0.01	21.99	0.00
29	0.07	0.01	0.93	0.13	18.42	0.00
31	0.08	0.01	0.07	0.02	3.99	0.00
33	0.05	0.01	0.63	0.01	7.24	0.00
35	0.18	0.00	0.44	0.00	10.97	0.00
36	0.12	0.00	0.30	0.01	26.11	0.00
38	0.21	0.01	0.53	0.07	23.13	0.00
39	0.10	0.01	0.34	0.00	23.09	0.01
40	0.07	0.00	0.51	0.00	20.24	0.00
41	0.16	0.01	0.68	0.02	37.07	0.01
42	0.12	0.00	0.80	0.05	36.48	0.00
43	0.12	0.00	1.09	0.01	42.64	0.00
44	0.16	0.01	0.93	0.01	41.96	0.00

Table B-3 Concentrations of ammonia, nitrite, and nitrate in T3 (i.e., no biofilters) with initial stocking density of 0.7 kg m^{-3} .

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
3	0.72	0.02	0.01	0.00	0.72	0.00
5	0.74	0.10	0.15	0.08	0.55	0.02
7	1.77	0.04	0.02	0.04	0.72	0.00
9	1.23	0.11	0.08	0.00	0.50	0.01
11	2.67	0.47	0.79	0.10	1.14	0.01
13	2.08	0.07	9.96	0.02	2.84	0.00
15	0.22	0.03	0.46	0.23	8.70	0.02
17	0.13	0.03	15.51	0.01	2.95	0.00
18	0.20	0.02	5.96	0.01	6.09	0.00
21	0.15	0.00	11.55	0.03	6.41	0.00
24	0.06	0.01	7.36	0.01	6.53	0.00
26	0.19	0.00	18.35	0.20	12.40	0.00
29	0.51	0.02	14.87	0.03	19.43	0.02
31	0.19	0.01	28.03	0.08	18.34	0.02
33	0.09	0.04	29.43	0.03	24.75	0.01
35	0.04	0.01	30.59	0.04	12.04	0.00
36	0.23	0.01	19.09	0.10	31.74	0.00
38	0.10	0.07	6.99	0.08	17.06	0.00
39	0.06	0.00	0.53	0.04	24.49	0.00
40	0.05	0.00	0.06	0.01	27.34	0.01
41	0.09	0.01	0.89	0.05	41.03	0.01
42	0.08	0.00	0.74	0.03	39.03	0.00
43	0.13	0.01	0.82	0.15	44.18	0.00
44	0.05	0.00	0.77	0.07	41.50	0.00

Table B-4 Concentrations of ammonia, nitrite, and nitrate in T4 (i.e., non-acclimated biofilters) with initial stocking density of 0.7 kg m^{-3} .

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
7	0.22	0.04	0.05	0.04	0.76	0.00
9	0.62	0.15	0.11	0.12	0.86	0.00
11	0.84	0.07	0.06	0.02	0.68	0.00
13	1.49	0.09	0.09	0.14	0.81	0.00
15	1.79	0.09	0.13	0.06	1.03	0.00
17	1.73	0.13	0.21	0.01	1.04	0.00
18	2.31	0.17	0.19	0.07	1.02	0.00
21	2.09	0.01	0.24	0.06	0.88	0.00
24	0.26	0.02	10.03	0.05	9.06	0.01
26	0.09	0.05	2.02	0.17	2.32	0.01
29	0.08	0.01	8.56	0.06	5.44	0.01
31	0.08	0.04	3.49	0.13	8.25	0.00
33	0.07	0.01	14.06	0.03	14.52	0.01
35	0.19	0.03	3.17	0.03	8.73	0.00
36	0.06	0.00	2.58	0.02	7.82	0.00
38	0.22	0.05	4.73	0.05	10.12	0.00
39	0.13	0.00	16.15	0.07	17.09	0.00
40	0.14	0.01	9.03	0.07	19.60	0.00
41	0.32	0.02	12.42	0.01	24.32	0.00
42	0.21	0.00	12.56	0.04	22.11	0.00
43	0.19	0.01	16.22	0.03	27.21	0.00
44	0.24	0.02	12.31	0.02	23.43	0.01

Table B-5 Concentrations of ammonia, nitrite, and nitrate in T1 (i.e., proposed aquaculture system) with initial stocking density of 3.0 kg m^{-3} .

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
0	1.03	0.02	0.00	0.01	1.55	0.00
2	2.54	0.08	0.11	0.01	2.79	0.01
4	1.33	0.01	0.93	0.01	5.53	0.82
6	0.50	0.02	0.28	0.00	7.01	1.09
8	1.36	0.05	0.18	0.01	12.78	0.28
10	0.19	0.00	0.27	0.06	17.60	0.46
12	0.23	0.03	0.30	0.01	18.18	0.48
14	0.08	0.01	0.45	0.00	21.76	0.61
16	0.13	0.00	0.29	0.01	25.46	0.74
18	0.13	0.01	0.37	0.01	27.40	0.81
20	0.10	0.01	0.10	0.02	30.17	0.91
22	0.20	0.02	0.11	0.04	41.17	0.56
24	0.32	0.02	0.35	0.00	41.81	0.57
26	0.18	0.01	0.26	0.07	44.21	0.62
28	0.16	0.01	0.17	0.01	50.19	0.73
30	0.08	0.00	0.22	0.01	42.98	0.60
32	0.23	0.01	0.26	0.02	50.99	0.74
34	0.04	0.00	0.10	0.01	53.41	0.78
36	0.34	0.02	0.28	0.00	56.89	0.85
38	0.03	0.00	0.39	0.01	59.82	0.90
40	0.41	0.02	0.61	0.03	59.82	0.90
41	0.09	0.01	0.11	0.00	59.98	0.90
43	0.23	0.04	0.10	0.01	62.23	0.94
45	0.13	0.00	0.11	0.03	61.85	0.94
47	0.37	0.00	0.44	0.01	78.65	0.77
49	0.02	0.01	0.11	0.00	78.31	0.76
51	0.08	0.00	0.15	0.03	66.10	1.01
53	0.26	0.03	0.11	0.00	92.84	0.94
55	0.01	0.00	0.10	0.01	90.13	0.90
57	0.12	0.01	0.43	0.02	108.00	1.12
59	0.38	0.01	0.37	0.00	97.11	0.99
61	0.44	0.00	0.52	0.01	82.38	0.67
63	0.24	0.01	0.22	0.01	89.95	0.76
65	0.32	0.00	0.45	0.02	90.59	0.76
67	0.39	0.00	0.52	0.02	84.28	0.69
69	0.56	0.01	0.32	0.00	90.05	0.76
71	0.15	0.00	0.42	0.00	87.07	0.61
73	0.26	0.00	0.35	0.02	68.72	0.49
75	0.12	0.01	0.48	0.01	78.53	0.58
77	0.10	0.01	0.11	0.00	51.83	0.41
79	0.21	0.00	0.49	0.00	60.53	0.40
81	0.21	0.01	0.46	0.00	54.47	0.23
83	0.35	0.01	0.51	0.00	27.21	0.02
85	0.06	0.00	0.09	0.01	8.56	0.13
87	0.63	0.00	0.31	0.01	9.87	0.10
89	0.37	0.00	0.20	0.01	12.64	0.08
91	0.86	0.00	0.16	0.01	12.00	0.08
93	2.28	0.00	0.21	0.00	12.54	0.09
95	6.92	0.01	0.15	0.01	12.50	0.09
97	23.47	0.00	0.53	0.00	14.35	0.08
99	42.10	0.00	0.14	0.00	14.03	0.08

Table B-6 Concentrations of ammonia, nitrite, and nitrate in T2 (i.e., proposed aquaculture system) with initial stocking density of 3.0 kg m⁻³.

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
0	0.84	0.07	0.00	0.01	1.35	0.001
2	2.31	0.06	0.05	0.01	2.75	0.005
4	0.76	0.02	0.77	0.01	5.70	0.01†
6	0.61	0.00	0.08	0.00	7.00	0.042
8	0.06	0.01	0.17	0.13	15.97	0.052
10	0.10	0.00	0.12	0.02	18.32	0.052
12	0.12	0.02	0.13	0.02	19.71	0.004
14	0.08	0.01	0.05	0.01	22.07	0.004
16	0.08	0.01	0.21	0.01	26.90	0.018
18	0.08	0.01	0.25	0.00	29.36	0.007
20	0.04	0.01	0.05	0.04	31.29	0.001
22	0.09	0.01	0.09	0.00	39.22	0.006
24	0.14	0.01	0.23	0.03	43.81	0.001
26	0.10	0.01	0.16	0.03	46.98	0.044
28	0.07	0.00	0.06	0.01	53.07	0.001
30	0.06	0.00	0.19	0.05	44.23	0.008
32	0.13	0.00	0.17	0.01	51.95	0.032
34	0.05	0.01	0.07	0.01	54.08	0.011
36	0.23	0.04	0.02	0.02	59.90	0.000
38	0.04	0.02	0.17	0.10	61.46	0.006
40	0.24	0.01	0.46	0.12	66.76	0.008
41	0.06	0.00	0.09	0.01	65.94	0.006
43	0.11	0.00	0.19	0.07	67.30	0.002
45	0.11	0.00	0.08	0.09	67.86	0.007
47	0.12	0.00	0.26	0.01	68.56	0.004
49	0.17	0.00	0.22	0.01	60.22	0.003
51	0.13	0.00	0.14	0.01	67.27	0.002
53	0.25	0.00	0.14	0.01	99.73	0.016
55	0.06	0.00	0.16	0.00	95.55	0.017
57	0.28	0.01	0.43	0.02	109.85	0.003
59	0.40	0.01	0.34	0.00	101.36	0.010
61	0.71	0.01	0.37	0.01	94.30	0.002
63	0.23	0.01	0.20	0.01	96.12	0.002
65	0.29	0.01	0.38	0.00	96.28	0.009
67	0.23	0.01	0.39	0.01	88.74	0.004
69	0.23	0.00	0.36	0.00	96.63	0.001
71	0.17	0.01	0.31	0.01	106.62	0.004
73	0.20	0.01	0.29	0.01	77.19	0.005
75	0.10	0.02	0.30	0.01	90.44	0.006
77	0.06	0.00	0.41	0.02	65.39	0.001
79	0.15	0.00	0.44	0.01	79.33	0.002
81	0.15	0.01	0.45	0.01	72.02	0.001
83	0.21	0.01	0.46	0.00	59.07	0.005
85	0.13	0.00	0.34	0.05	48.71	0.001
87	0.26	0.00	0.27	0.00	53.76	0.004
89	0.26	0.00	0.32	0.00	53.76	0.004
91	0.35	0.00	0.44	0.01	30.75	0.002
93	0.33	0.01	0.20	0.01	15.75	0.001
95	0.41	0.00	0.24	0.00	14.61	0.001
97	0.55	0.00	0.17	0.00	12.16	0.000
99	0.31	0.00	0.18	0.00	9.00	0.001

Table B-7 Concentrations of ammonia, nitrite, and nitrate in T3 (i.e., proposed aquaculture system) with initial stocking density of 1.7 kg m^{-3} .

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
0	0.42	0.03	0.00	0.00	1.16	0.00
2	0.61	0.04	0.03	0.01	2.48	0.00
4	1.70	0.46	0.06	0.00	3.78	0.00
6	0.08	0.00	0.37	0.00	4.89	0.00
8	0.02	0.00	0.02	0.01	8.49	0.04
10	0.01	0.00	0.02	0.01	10.31	0.01
12	0.05	0.02	0.03	0.00	13.35	0.01
14	0.01	0.00	0.01	0.01	13.32	0.01
16	0.02	0.00	0.06	0.01	15.92	0.00
18	0.04	0.02	0.06	0.00	19.15	0.01
20	0.03	0.02	0.03	0.02	19.61	0.01
22	0.08	0.01	0.05	0.00	22.19	0.01
24	0.09	0.01	0.06	0.02	24.93	0.02
26	0.05	0.01	0.06	0.00	32.35	0.02
28	0.04	0.00	0.03	0.00	31.12	0.01
30	0.04	0.00	0.10	0.00	27.79	0.02
32	0.06	0.00	0.07	0.01	30.16	0.00
34	0.06	0.00	0.12	0.00	32.73	0.02
36	0.07	0.01	0.09	0.01	37.29	0.00
38	0.09	0.03	0.12	0.08	38.74	0.01
40	0.06	0.01	0.19	0.17	47.75	0.00
41	0.02	0.01	0.02	0.00	47.17	0.01
43	0.01	0.00	0.05	0.00	53.31	0.00
45	0.05	0.01	0.11	0.09	54.33	0.00
47	0.04	0.00	0.12	0.02	52.62	0.00
49	0.04	0.01	0.08	0.01	50.67	0.02
51	0.06	0.01	0.06	0.00	60.73	0.00
53	0.09	0.01	0.09	0.00	72.31	0.00
55	0.01	0.00	0.11	0.01	68.62	0.01
57	0.13	0.00	0.39	0.03	109.15	0.00
59	0.16	0.02	0.19	0.02	89.65	0.00
61	0.23	0.00	0.21	0.02	57.46	0.00
63	0.14	0.01	0.15	0.01	69.30	0.01
65	0.17	0.01	0.14	0.01	72.14	0.01
67	0.09	0.01	0.16	0.02	69.55	0.00
69	0.09	0.01	0.11	0.00	76.34	0.00
71	0.08	0.01	0.13	0.01	84.46	0.00
73	0.08	0.00	0.12	0.01	60.99	0.00
75	0.06	0.01	0.13	0.01	77.18	0.00
77	0.05	0.00	0.31	0.07	83.66	0.00
79	0.04	0.00	0.15	0.01	76.74	0.00
81	0.04	0.00	0.16	0.00	76.69	0.00
83	0.08	0.01	0.17	0.00	73.99	0.00
85	0.09	0.00	0.17	0.01	73.99	0.00
87	0.10	0.01	0.16	0.00	105.07	0.00
89	0.17	0.00	0.29	0.00	100.77	0.00
91	0.17	0.00	0.41	0.00	91.67	0.00
93	0.12	0.00	0.16	0.00	82.14	0.00
95	0.16	0.00	0.24	0.00	99.96	0.00
97	0.07	0.00	0.23	0.00	88.74	0.00
99	0.12	0.00	0.53	0.00	82.99	0.00

Table B-8 Concentrations of ammonia, nitrite, and nitrate in T4 (i.e., suspended-growth system) with initial stocking density of 3.0 kg m^{-3} .

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
0	0.98	0.10	0.00	0.00	0.68	0.06
2	2.82	0.06	0.01	0.00	0.86	0.03
4	6.34	0.08	0.12	0.08	1.07	0.01
6	8.34	0.18	0.06	0.00	1.19	0.03
8	15.80	0.06	0.25	0.03	1.47	0.09
10	18.30	0.10	0.52	0.08	4.35	0.60
12	0.05	0.01	5.24	0.10	20.12	0.55
14	0.08	0.02	5.43	0.01	24.20	0.69
16	0.08	0.01	4.97	0.04	27.46	0.81
18	0.08	0.03	5.46	0.11	31.49	0.96
20	0.05	0.01	5.32	0.30	31.34	0.95
22	0.10	0.01	3.90	0.16	31.80	0.39
24	0.07	0.00	4.54	0.02	33.27	0.42
26	0.07	0.01	4.56	0.05	36.09	0.47
28	0.10	0.01	4.33	0.07	39.05	0.53
30	0.10	0.00	5.03	0.11	33.37	0.42
32	0.11	0.01	4.96	0.06	41.94	0.58
34	0.10	0.00	4.80	0.09	35.79	0.47
36	0.01	0.00	0.12	0.00	36.81	0.48
38	0.05	0.01	0.18	0.04	39.33	0.53
40	0.02	0.01	0.29	0.18	41.73	0.57
41	0.05	0.02	0.09	0.03	45.22	0.64
43	0.01	0.00	0.04	0.00	47.57	0.68
45	0.01	0.00	0.00	0.01	49.33	0.71
47	0.02	0.00	0.05	0.01	54.24	0.80
49	0.02	0.00	0.07	0.01	51.28	0.75
51	0.01	0.00	0.05	0.01	59.66	0.90
53	0.01	0.01	0.03	0.01	81.98	0.81
55	0.01	0.01	0.09	0.04	74.81	0.72
57	0.03	0.01	0.07	0.01	109.61	1.14
59	0.08	0.01	0.06	0.02	80.18	0.78
61	17.24	0.01	0.50	0.02	83.69	0.69
63	7.23	0.03	0.54	0.01	79.68	0.64
65	10.39	0.01	0.45	0.01	90.91	0.77
67	9.45	0.00	0.37	0.01	88.69	0.74
69	1.73	0.00	0.38	0.01	99.30	0.86
71	0.64	0.00	0.23	0.00	116.62	0.88
73	1.14	0.01	0.22	0.01	91.74	0.71
75	0.51	0.00	0.27	0.00	107.24	0.86
77	0.35	0.02	0.21	0.00	58.82	0.50
79	0.46	0.01	0.34	0.00	109.18	0.88
81	0.46	0.00	0.34	0.00	109.65	0.88
83	0.17	0.01	0.21	0.01	110.69	0.87
85	0.08	0.01	0.14	0.00	109.76	0.86
87	0.15	0.00	0.14	0.00	153.13	0.82
89	0.39	0.01	0.22	0.00	158.15	0.85
91	0.33	0.00	0.15	0.01	149.23	0.79
93	0.14	0.00	0.11	0.00	133.61	0.74
95	0.40	0.00	0.51	0.01	141.47	0.80
97	0.70	0.01	0.14	0.00	138.49	0.81
99	0.21	0.00	0.49	0.01	135.89	0.79

Table B-9 Concentrations of ammonia, nitrite, and nitrate in L1 (i.e., proposed aquaculture system; outdoor; biofilter cleaning) with initial stocking density of 5.0 kg m⁻³.

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
0	0.02	0.01	0.01	0.01	0.81	0.03
2	1.52	0.01	0.34	0.04	2.47	0.00
4	0.39	0.09	1.15	0.02	7.95	0.31
6	0.26	0.03	0.15	0.09	7.37	0.13
8	0.23	0.03	0.33	0.15	17.78	0.07
10	0.10	0.04	0.26	0.01	22.31	0.03
12	0.29	0.15	0.13	0.14	26.77	0.20
14	0.30	0.03	0.16	0.07	27.38	0.01
16	0.42	0.08	1.95	0.29	28.73	0.31
18	0.36	0.09	1.19	0.35	29.01	0.35
20	0.29	0.06	0.90	0.02	40.58	1.04
22	0.37	0.11	0.98	0.46	43.71	0.61
24	0.37	0.12	0.71	0.09	45.15	0.00
26	0.25	0.05	1.25	0.02	54.28	2.68
28	0.44	0.17	1.16	0.10	56.41	3.84
30	0.42	0.08	0.56	0.04	54.80	0.05
32	0.25	0.17	0.91	0.02	67.39	2.91
34	0.32	0.07	0.99	0.04	69.59	1.25
36	1.17	0.17	6.90	0.17	66.06	3.58
38	1.36	0.28	1.84	0.16	86.69	4.75
40	1.16	0.45	1.71	0.14	86.67	7.00
42	1.03	0.07	4.23	0.10	107.81	0.52
44	1.34	0.07	4.37	0.19	109.15	0.69
46	0.29	0.02	4.47	0.04	123.63	4.80
48	0.44	0.04	2.21	0.19	121.56	2.29
50	0.21	0.03	0.84	0.14	133.40	1.00
54	0.38	0.01	0.52	0.15	124.19	2.29
56	1.47	0.23	1.69	0.04	135.68	7.80
58	1.32	0.22	0.56	0.07	155.83	6.53
60	3.35	0.26	0.28	0.14	148.72	6.61
62	0.81	0.07	0.68	0.02	167.37	0.93
64	2.90	0.20	0.61	0.01	174.93	8.47
65	1.36	0.05	0.79	0.04	155.35	0.96
68	1.03	0.04	0.38	0.01	157.22	6.02
70	0.99	0.15	1.29	0.02	216.39	0.35
72	0.55	0.09	0.20	0.03	212.90	8.33
74	0.55	0.01	0.30	0.01	202.87	1.64
76	1.62	0.10	1.22	0.05	272.12	0.82
78	2.15	0.20	1.61	0.03	233.96	11.57
80	2.05	0.02	1.51	0.10	224.27	2.14
82	1.05	0.04	0.98	0.02	213.08	3.22
84	2.60	0.04	1.54	0.04	223.80	0.48
86	1.12	0.13	1.86	0.10	259.74	11.90
89	1.73	0.03	2.40	0.16	252.27	1.09
91	1.28	0.13	1.79	0.16	213.54	1.38
93	1.17	0.18	2.04	0.09	241.06	0.11
95	0.65	0.03	2.61	0.24	241.47	6.52
97	0.88	0.03	2.51	0.23	236.04	6.39
99	1.12	0.09	2.68	0.27	215.13	0.25

Table B-10 Concentrations of ammonia, nitrite, and nitrate in L2 (i.e., proposed aquaculture system; outdoor, without biofilter cleaning) with initial stocking density of 5.0 kg m⁻³.

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
0	0.03	0.02	0.01	0.01	0.72	0.00
2	1.96	0.07	0.28	0.02	2.23	0.00
4	0.67	0.04	1.99	0.18	7.98	0.42
6	0.30	0.03	0.02	0.00	7.36	0.01
8	0.38	0.16	0.28	0.05	18.50	0.04
10	0.27	0.03	0.23	0.13	22.49	0.36
12	0.29	0.07	0.05	0.07	23.33	0.18
14	0.55	0.02	0.38	0.04	26.47	0.02
16	0.50	0.18	0.77	0.17	27.96	0.17
18	0.29	0.04	0.47	0.05	27.90	0.28
20	0.51	0.09	0.80	0.07	40.81	0.32
22	0.96	0.67	0.84	0.11	42.88	1.05
24	0.60	0.24	0.51	0.03	41.20	1.18
26	0.39	0.09	0.72	0.11	57.61	2.22
28	0.60	0.01	0.77	0.05	53.40	0.65
30	0.65	0.11	0.47	0.03	55.78	0.14
32	0.13	0.03	0.54	0.03	65.92	0.22
34	0.43	0.06	0.79	0.02	69.24	2.80
36	1.21	0.08	3.57	0.10	69.63	0.42
38	0.86	0.02	1.00	0.07	75.47	3.99
40	0.65	0.04	0.69	0.04	84.49	0.38
42	1.01	0.20	2.64	0.04	104.82	0.52
44	1.15	0.18	3.31	0.08	107.77	1.26
46	0.27	0.04	1.84	0.17	119.69	0.64
48	0.40	0.05	1.10	0.13	121.61	3.36
50	0.29	0.04	0.58	0.18	127.68	5.65
54	0.50	0.04	0.47	0.00	134.92	5.01
56	1.64	0.13	2.23	0.03	132.95	1.50
58	1.53	0.14	0.84	0.05	149.70	10.39
60	1.16	0.03	0.42	0.05	144.29	4.98
62	2.30	0.18	1.32	0.05	161.38	2.51
64	5.30	0.59	1.61	0.12	167.70	1.58
65	8.26	0.87	2.02	0.10	142.62	2.43
68	8.69	0.14	3.31	0.16	142.78	1.31
70	1.94	0.12	4.56	0.61	211.00	3.99
72	0.66	0.37	0.59	0.14	184.37	5.51
74	0.67	0.04	0.28	0.01	211.82	5.16
76	1.32	0.85	0.65	0.01	161.23	1.17
78	1.10	0.12	0.98	0.06	215.38	0.13
80	1.18	0.05	0.87	0.03	205.78	6.16
82	0.82	0.05	0.71	0.01	189.62	5.61
84	1.94	0.15	1.44	0.04	200.84	2.15
86	0.87	0.08	0.87	0.01	218.54	11.90
89	0.87	0.06	1.46	0.10	244.81	15.05
91	0.77	0.14	1.30	0.20	210.00	6.38
93	1.02	0.05	1.42	0.09	222.76	6.90
95	1.36	1.74	0.89	0.05	232.81	2.87
97	0.38	0.02	0.30	0.04	242.95	2.61
99	0.37	0.05	0.67	0.04	218.35	6.76

Table B-11 Concentrations of ammonia, nitrite, and nitrate in D1 (i.e., proposed aquaculture system; dark; biofilter cleaning) with initial stocking density of 5.0 kg m⁻³.

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
0	0.02	0.01	0.01	0.00	0.84	0.11
2	3.30	0.11	0.09	0.01	1.72	0.00
4	2.94	0.26	1.65	0.01	6.77	0.02
6	0.68	0.02	1.38	0.07	7.48	0.15
8	0.16	0.11	0.21	0.01	18.68	0.04
10	0.26	0.02	0.41	0.09	22.19	0.05
12	0.14	0.23	0.03	0.05	22.92	0.73
14	0.10	0.04	0.05	0.09	25.30	0.62
16	0.34	0.08	0.45	0.21	27.37	0.39
18	0.27	0.08	0.78	0.21	28.75	1.18
20	0.31	0.14	0.20	0.02	35.82	3.47
22	0.47	0.12	0.51	0.05	41.94	0.94
24	0.30	0.11	0.58	0.06	44.73	1.81
26	0.33	0.09	0.97	0.02	56.44	4.67
28	0.49	0.10	1.12	0.08	54.59	3.95
30	0.52	0.04	0.50	0.02	56.85	0.16
32	0.12	0.01	0.36	0.02	60.33	4.63
34	0.20	0.06	0.65	0.01	65.82	0.53
36	0.61	0.02	1.99	0.02	67.92	2.99
38	0.70	0.08	0.81	0.02	84.12	0.21
40	0.56	0.18	0.43	0.01	81.37	1.18
42	0.42	0.14	0.66	0.11	99.47	5.32
44	0.46	0.07	0.87	0.04	105.59	2.18
46	0.15	0.03	0.44	0.08	112.65	1.43
48	0.26	0.01	0.64	0.17	118.62	0.43
50	0.12	0.00	0.40	0.16	131.12	1.79
54	0.32	0.02	0.29	0.02	130.16	0.00
56	1.34	0.05	1.21	0.04	136.13	1.00
58	0.38	0.10	0.16	0.04	107.73	5.84
60	1.03	0.08	0.37	0.10	141.68	1.80
62	0.36	0.09	0.39	0.04	165.86	4.00
64	0.62	0.01	0.49	0.03	159.54	4.93
65	0.67	0.02	0.82	0.07	153.81	0.17
68	0.96	0.04	1.28	0.03	148.46	0.26
70	2.57	0.07	2.52	0.05	229.74	10.56
72	1.02	0.02	1.96	0.02	251.80	0.00
74	2.48	0.32	1.61	0.06	250.97	1.17
76	2.30	0.23	1.41	0.03	172.93	0.59
78	1.94	0.07	2.41	0.03	216.27	1.38
80	2.06	0.30	2.25	0.06	210.04	1.89
82	1.81	0.20	1.24	0.03	182.36	0.60
84	1.58	0.28	1.84	0.08	218.57	3.10
86	1.29	0.18	1.94	0.06	235.79	4.73
89	0.92	0.19	1.42	0.01	215.19	4.25
91	1.11	0.17	2.26	0.09	184.42	5.26
93	0.88	0.13	2.04	0.02	214.47	0.46
95	0.25	0.02	1.20	0.01	213.46	7.56
97	0.56	0.03	1.49	0.01	213.55	0.13
99	0.64	0.09	2.42	0.26	207.30	5.90

Table B-12 Concentrations of ammonia, nitrite, and nitrate in D2 (i.e., proposed aquaculture system; dark; without biofilter cleaning) with initial stocking density of 5.0 kg m⁻³.

Day	Ammonia (mg N L ⁻¹)		Nitrite (mg N L ⁻¹)		Nitrate (mg N L ⁻¹)	
	Average	SD	Average	SD	Average	SD
0	0.02	0.02	0.01	0.01	0.85	0.09
2	2.44	0.61	0.12	0.03	1.65	0.00
4	2.53	0.09	1.92	0.05	6.80	0.18
6	0.19	0.01	2.77	0.09	7.48	0.11
8	0.33	0.37	0.51	0.14	18.00	0.07
10	0.10	0.06	0.40	0.03	22.41	0.21
12	0.24	0.18	0.01	0.01	23.05	0.14
14	0.13	0.02	0.07	0.07	27.51	0.16
16	0.25	0.03	0.26	0.09	25.32	1.57
18	0.29	0.09	0.55	0.05	28.39	0.30
20	0.31	0.04	0.52	0.01	40.62	0.43
22	0.46	0.09	0.49	0.04	43.62	1.84
24	0.31	0.14	0.44	0.00	45.69	0.35
26	0.22	0.04	0.64	0.02	53.59	3.05
28	0.37	0.08	1.05	0.05	57.70	1.50
30	0.37	0.13	0.44	0.03	59.02	0.51
32	0.14	0.01	0.35	0.01	69.59	0.36
34	0.31	0.06	0.76	0.00	70.06	3.08
36	0.43	0.06	1.49	0.03	67.33	4.05
38	0.26	0.05	0.34	0.01	75.93	1.11
40	0.53	0.19	0.31	0.00	83.14	2.70
42	0.33	0.01	0.44	0.04	106.72	4.47
44	0.47	0.05	0.85	0.03	109.35	1.43
46	0.18	0.01	0.47	0.21	121.91	2.65
48	0.31	0.03	0.62	0.14	140.44	6.66
50	0.13	0.00	0.33	0.09	136.13	4.44
54	0.37	0.07	1.13	0.16	117.61	2.29
56	1.20	0.14	1.75	0.16	146.66	13.31
58	0.57	0.09	0.60	0.07	146.66	2.49
60	0.67	0.23	0.45	0.14	148.06	1.37
62	0.59	0.04	0.91	0.09	163.95	0.19
64	0.62	0.01	1.01	0.03	175.13	5.40
65	0.74	0.02	1.05	0.02	148.83	1.65
68	0.72	0.03	0.71	0.03	156.73	2.53
70	1.27	0.07	1.56	0.12	228.99	10.91
72	0.50	0.06	0.51	0.01	182.22	1.76
74	0.76	0.12	0.70	0.03	153.02	0.35
76	2.08	0.12	2.33	0.09	222.27	0.94
78	2.00	0.22	2.12	0.05	188.53	1.38
80	1.28	0.08	1.69	0.07	191.20	3.90
82	1.10	0.13	1.21	0.01	182.36	0.60
84	1.91	0.49	1.94	0.09	199.58	2.27
86	0.83	0.22	2.16	0.03	187.47	3.40
89	4.16	0.89	2.60	0.21	187.81	4.13
91	1.93	0.20	2.36	0.05	151.95	3.63
93	1.36	1.80	1.06	0.07	152.60	1.72
95	0.20	0.04	0.47	0.01	140.00	0.91
97	0.30	0.02	0.95	0.03	162.03	0.26
99	0.30	0.04	1.07	0.06	157.04	2.71

Table B-13 Tilapia growth data during the zero-water exchanged cultivation for initial stocking density of 3.0 kg m^{-3}

Day	T1*				T2*			
	Weight, g		Length, cm		Weight, g		Length, cm	
	Average	SD	Average	SD	Average	SD	Average	SD
0	58.93	5.31	14.85	0.63	55.74	7.17	14.72	0.65
12	85.00	17.16	15.60	0.88	69.00	11.01	14.90	0.57
27	127.00	35.29	17.05	1.16	107.00	24.97	16.75	1.14
43	146.00	41.95	17.98	1.94	125.00	30.28	17.67	1.45
54	175.00	74.27	20.10	2.28	132.00	41.04	18.40	1.98
75	282.00	76.85	22.70	1.96	199.00	37.25	20.70	2.08
92	242.00	73.76	22.85	2.44	195.00	61.87	20.45	2.33
99	-	-	-	-	-	-	-	-

Day	T3				T4			
	Weight, g		Length, cm		Weight, g		Length, cm	
	Average	SD	Average	SD	Average	SD	Average	SD
0	55.00	7.60	14.56	0.63	52.78	10.03	14.49	0.82
12	72.00	13.03	15.60	0.74	77.00	15.67	15.37	1.03
27	98.00	22.80	16.80	1.35	99.00	17.92	16.30	1.18
43	133.00	45.77	18.50	2.15	144.00	38.93	18.45	1.38
54	166.00	48.27	19.70	2.25	135.00	28.38	19.45	1.70
75	178.00	26.83	21.60	1.52	176.00	29.14	20.45	1.30
92	244.00	54.13	22.40	2.25	182.00	30.48	20.55	1.34
99	253.18	51.72	22.85	2.24	197.24	37.43	21.22	1.54

(*) Measured on day 85 before tilapia mortality

Table B-14 Tilapia growth data during the zero-water exchanged cultivation for the

Day	L1				L2			
	Weight, g		Length, cm		Weight, g		Length, cm	
	Average	SD	Average	SD	Average	SD	Average	SD
0	34.17	5.27	12.40	0.64	31.17	5.72	12.53	0.61
18	50.13	9.80	13.99	0.79	54.25	11.88	14.08	1.15
34	75.58	17.60	15.71	1.10	74.21	19.74	15.65	1.46
51	104.35	25.05	17.23	1.30	101.74	27.65	16.96	1.42
71	154.84	42.95	19.15	1.83	136.48	40.76	18.65	1.93
103	212.68	68.68	21.41	2.23	177.16	58.55	20.18	2.29

Day	D1				D2			
	Weight, g		Length, cm		Weight, g		Length, cm	
	Average	SD	Average	SD	Average	SD	Average	SD
0	33.12	5.18	12.27	0.64	33.27	4.92	12.40	0.62
18	51.31	10.45	14.03	0.99	48.38	8.55	13.03	2.82
34	67.18	16.99	14.94	1.05	59.32	11.77	14.42	0.76
51	81.08	24.49	15.80	1.51	84.67	24.33	16.06	1.64
71	132.21	33.67	18.05	1.42	132.51	33.54	18.05	1.55
103	167.73	66.66	19.75	2.33	169.15	47.60	19.89	1.80

initial stocking density of 5.0 kg m^{-3} .

Table B-15 Physical parameters measured from T1 and T2 tilapia cultivating tanks for the initial stocking density 3.0 kg m^{-3}

Day	T1			T2		
	Alkalinity	pH	Temp.	Alkalinity	pH	Temp.
	$\text{mg L}^{-1} \text{CaCO}_3$		$^{\circ}\text{C}$	$\text{mg L}^{-1} \text{CaCO}_3$		$^{\circ}\text{C}$
8		7.90	28.10		8.12	28.00
10		8.12	28.20		8.04	28.50
14		7.76	28.10		7.75	28.10
18	40	7.72	27.60	40	7.47	28.00
20	80	8.31	28.00	70	8.34	28.10
24	70	6.73	28.50	60	6.70	28.50
26		7.41	27.50		7.42	27.90
28	60	7.55	27.50	50	7.46	27.70
32	80	7.03	28.80	70	6.67	28.80
36	90	7.44	28.60	90	7.27	28.30
38	110	7.58	27.30	80	7.35	27.50
40	80	7.52	27.50	80	7.04	27.80
47		7.12	27.10		6.83	27.30
49	80	7.43	27.20	50	6.82	27.50
51	80	7.63	27.00	60	7.03	27.40
53	90	7.57	26.20	80	7.38	26.30
57		7.49	28.60		7.39	28.40
61	80	7.03	28.80	70	6.67	28.80
63		7.28	26.90		7.42	26.90
65		7.31	28.00		7.34	28.00
67	140	8.00	27.10	150	8.08	27.40
69		7.87	26.90		7.97	27.10
71		8.07	26.90		8.09	27.30
73	200	8.23	27.30	200	8.18	27.70
75		8.02	27.70		8.06	28.00
79		7.88	27.20		7.85	27.20
81		8.13	27.50		8.07	27.30
83	180	8.22	28.10	160	8.19	28.10
85		8.23	28.70		8.22	28.70
87		8.38	28.20		8.49	27.30
89	160	8.21	27.70	150	8.37	27.90
91		8.27	27.90		8.35	27.70
93		8.25	27.30		8.62	27.40
95	150	8.25	27.80	150	8.51	27.70
97		8.00	27.80		8.50	28.00
99		8.00	30.00		8.50	28.90

Table B-16 Physical parameters measured from T3 and T4 tilapia cultivating tanks for the initial stocking density of 3.0 kg m^{-3}

Day	T3			T4		
	Alkalinity	pH	Temp.	Alkalinity	pH	Temp.
	$\text{mg L}^{-1}\text{CaCO}_3$		$^{\circ}\text{C}$	$\text{mg L}^{-1}\text{CaCO}_3$		$^{\circ}\text{C}$
8		8.25	28.10		8.34	28.10
10		8.30	28.50		8.33	28.50
14		8.05	28.10		7.75	28.00
18	40	8.00	28.00	40	7.20	28.00
20	100	8.68	28.00	90	8.09	27.80
24	100	7.19	28.00	100	6.87	28.80
26		7.70	27.90		7.21	27.50
28	70	7.80	27.90	70	7.35	27.60
32	90	7.30	28.80	100	6.22	27.80
36	110	7.58	28.40	130	7.44	28.10
38	110	7.86	27.50	140	7.52	27.20
40	100	7.65	27.60	150	7.49	27.50
47		7.61	27.40		7.39	27.20
49	70	7.74	27.50	60	7.53	27.10
51	90	7.77	27.50	50	7.46	27.20
53	90	7.68	26.30	100	7.61	26.20
57		7.96	28.40		7.66	28.20
61	90	7.30	28.80	100	6.22	27.80
63		7.53	29.90		7.16	26.90
65		7.56	28.10		7.19	27.90
67	110	8.24	27.50	120	7.65	27.30
69		8.09	27.10		6.83	26.90
71		8.16	27.30		6.87	27.10
73	130	8.18	27.80	70	6.86	27.50
75		8.02	28.00		6.72	27.80
79		7.68	27.10		6.63	27.20
81		7.82	27.60		7.00	27.50
83		7.81	287.00		7.98	28.00
85	120	7.86	28.60	120	7.02	28.60
87		8.06	27.30		7.17	27.10
89		7.97	27.80		7.13	27.60
91		8.04	27.60		7.11	27.20
93		8.12	27.40		7.20	27.20
95	150	7.96	27.50	150	7.06	27.50
97		8.00	28.20		7.00	27.80
99		8.00	28.90		7.00	29.90

Table B-17 Physical parameters measured from L1 and L2 tilapia cultivating tanks for the initial stocking density of 5.0 kg m⁻³.

Day	L1			L2		
	Alkalinity	pH	Temp.	Alkalinity	pH	Temp.
	mg L ⁻¹ CaCO ₃		°C	mg L ⁻¹ CaCO ₃		°C
2		8.43	28.40		8.46	28.20
4	120	8.52	27.80	120	8.46	27.60
6		8.48	27.80		8.52	27.40
8	110	8.31	27.60	120	8.53	27.50
10		8.57	27.80		8.25	27.70
12		8.77	27.30		8.00	28.40
18	60	7.53	29.50	60	7.67	30.10
24		7.80	28.00		7.50	28.00
26	90	7.47	26.10		7.55	26.80
30		7.56	26.70		7.55	26.80
32		7.52	26.20		7.48	25.90
34		7.42	26.10	80	7.36	25.90
36		8.05	27.80		7.77	28.60
38	80	7.24	27.20	110	7.30	27.80
50		7.36	27.00		7.40	26.50
54		7.26	26.30		7.20	27.10
56	50	7.16	27.20	100	7.24	27.90
60		6.91	27.30	60	7.01	27.90
62	40	6.43	26.10		6.79	26.70
64	90	7.02	27.00	90	7.04	27.50
68		6.69	27.50		7.20	28.00
70	50	6.83	27.70	140	7.19	28.10
72	80	6.86	29.30	110	7.11	29.30
78	50	6.69	26.80	90	7.01	27.20
80	100	7.00	27.10	100	6.98	27.40
82		6.78	26.10		6.88	25.80
84		6.80	26.50	80	6.83	23.30
86	60	6.75	23.30		7.50	23.80
89	90	7.37	24.10	100	7.23	23.80
91		7.52	25.50	90	7.20	26.30
93		7.51	27.00		7.15	27.60
95	100	7.54	27.30	120	7.40	28.10
99		7.40	29.20	100	7.87	27.90

Table B-18 Physical parameters measured from D1 and D2 tilapia cultivating tanks for the initial stocking density of 5.0 kg m^{-3} .

Day	D1			D2		
	Alkalinity	pH	Temp.	Alkalinity	pH	Temp.
	$\text{mg L}^{-1}\text{CaCO}_3$		$^{\circ}\text{C}$	$\text{mg L}^{-1}\text{CaCO}_3$		$^{\circ}\text{C}$
2	120	7.64	27.00	120	8.24	28.50
4	120	7.50	24.50		8.53	28.20
6		7.39	24.30		8.23	27.90
8	120	7.42	25.90	110	8.51	27.90
10		7.82	27.50		8.05	27.80
12		7.34	26.40		8.17	27.30
18	60	7.71	27.00	60	7.56	26.90
24		7.50	24.50		7.50	24.80
26	90	7.39	24.30	90	7.50	24.40
30		7.42	25.90		7.48	25.60
32		7.82	27.50		7.58	27.90
34	60	7.34	26.40		7.38	26.70
36		7.71	27.00		7.50	26.90
38	60	7.89	25.10	60	7.40	25.50
50		7.50	25.70		7.40	25.20
54		7.44	23.80	60	7.54	23.90
56	50	7.34	24.50	100	7.42	23.80
60	70	7.00	25.70		6.77	24.60
62	50	6.46	24.70	90	7.13	24.40
64	90	7.19	24.60	90	7.31	25.00
68		6.83	25.70		7.22	25.60
70	80	7.08	26.10	150	7.21	25.90
72	100	7.14	26.90	140	7.32	26.60
78	70	7.08	26.10	140	7.42	25.70
80	90	7.03	25.00	100	7.39	25.10
82		7.00	24.60		7.56	24.70
84	90	7.39	21.20		7.65	24.80
86	100	7.32	22.80		7.78	22.30
89	90	7.86	23.30	110	7.56	21.60
91		7.63	25.70		7.85	23.10
93	120	7.87	25.80		7.82	25.10
95	100	7.95	26.20	120	8.04	27.30
99		8.03	26.70		8.10	26.30

Appendix C

Calculation

C-1 Calculation of Shrimp Diets Required for Biofilter Acclimation

Shrimp diets contain 40% proteins by weight and it is approximated that 1 g of protein contain 0.16 g of nitrogen. To obtain 2 mg N L⁻¹ of nitrogen in 800 L of water, the amount of shrimp diet required is:

$$\frac{2 \times 800}{0.16 \times 1000 \times 0.4} = 25 \text{ g of shrimp diet.}$$

C-2 Calculation of Ammonium Degradation Rate during Batch Experiment

The length of Biocord™ biofilters used to determine the rate of ammonium degradation was 10 cm. The data indicated that biofilters were able to remove 4 mg N L⁻¹ from 6 L water within 50 hours. The Biocord™ biofilters have the specific surface area of 2.8 m² m⁻¹. The rate of ammonium degradation can be calculated as followed:

Total amount of nitrogen removed per day:

$$((4 \times 6) \div 50) \times 24 = 11.52 \text{ mg N day}^{-1}$$

Total amount of nitrogen removed per unit length of biofilter per day:

$$11.52 \div 0.10 = 115.20 \text{ mg N m}^{-1} \text{ day}^{-1}$$

Total amount of nitrogen removed per unit area of biofilters per day:

$$115.20 \div 2.8 = 41.14 \text{ mg N m}^{-2} \text{ day}^{-1}$$

C-3 Calculation of Nitrogen of Tilapia Feeds

Tilapia feeds contains 30% protein. Tilapia was fed at 3% of total fish weight per day. Assuming 5 tilapia with average weight of 113 was reared in 450 L tank, the amount of nitrogen input from feed can be calculated as

Amount of nitrogen from feed per day:

$$565 \times 0.03 \times 0.30 \times 0.16 = 0.81 \text{ g N day}^{-1}$$

Concentration of nitrogen from feeds that is delivered per day in 450 L tank is:

$$0.81 \div 450 = 0.0018 \text{ g N L}^{-1} \text{ or } 1.8 \text{ mg N L}^{-1}$$

C-4 Calculation of Biofilter Required for the Proposed Aquaculture System

According to section C-2, the rate of ammonium degradation is $115.20 \text{ mg N m}^{-1} \text{ day}^{-1}$. For the case of initial stocking density of 0.7 kg m^{-3} , if targeting the final fish density at 2.5 kg m^{-3} , then for the purposed of the calculation, the fish density would be $(0.7+2.5)/2 = 1.6 \text{ kg m}^{-3}$, that is equivalent to 0.8 kg in 500 L tank.

From the given fish biomass, determine the amount of nitrogen waste that would be produced daily assuming that the feeds contain 30% proteins and fish was fed at 3% of total weight.

Amount of nitrogen waste per day:

$$0.8 \times 1,000 \times 0.3 \times 0.03 \times 0.16 = 1.152 \text{ g N day}^{-1}$$

Therefore, the required biofilter length is:

$$(1.152 \times 1,000) \div 115.2 = 10 \text{ m.}$$

C-5 Nitrogen Balance Calculation

Using L1 as an example, the nitrogen balance equation can be written as:

Nitrogen entering the system – Nitrogen leaving the system = Nitrogen accumulated in the system

Nitrogen entering the system

Nitrogen entering the system came from three sources; inorganic nitrogen originally in water, nitrogen in tilapia feed, and nitrogen in tilapia. The calculation herein uses L1 as example. The nitrogen originally in water was the total inorganic nitrogen, which is the summer of $\text{NH}_4^+\text{-N}$, $\text{NO}_2^-\text{-N}$, and $\text{NO}_3^-\text{-N}$. Note that the nitrate measuring method, UV Screening, reported the total nitrogen concentrations as a sum of nitrogen from nitrite and nitrate. Therefore, the amount of dissolved inorganic nitrogen at the beginning of the experiment was;

$$\begin{aligned} \text{TIN} &= \text{NH}_4^+\text{-N} + \text{NO}_2^-\text{-N} + (\text{NO}_3^-\text{-N} - \text{NO}_2^-\text{-N}) \\ &= [0.015 + 0.007 + (0.812 - 0.007)] \times 500 = 0.42 \text{ g N} \end{aligned}$$

Nitrogen originated from tilapia feed is another source of nitrogen input. The calculation in Appendix C-3 can be referred for nitrogen determination. For this example, the total nitrogen input was calculated at 750.91 g N. Nitrogen can also be found in protein in tilapia biomass. Tilapia weight on the first day of cultivation was 2,269 g. According to Mutita (2003), tilapia contained approximately 48.87% protein content, and the dried content of tilapia biomass was about 0.6 of wet biomass. Therefore, nitrogen in tilapia was:

$$\text{Nitrogen in tilapia} = (2,269)(0.6)(0.4887)(0.6) = 29.56 \text{ g N}$$

Nitrogen leaving the system

The amount of nitrogen at the end of the experiment can be categorized into three groups; dissolved inorganic nitrogen, nitrogen in tilapia biomass, and unaccountable portion. Dissolved inorganic nitrogen in water was;

$$\begin{aligned} \text{TIN in water} &= \text{NH}_4^+ \text{-N} + \text{NO}_2^- \text{-N} + (\text{NO}_3^- \text{-N} - \text{NO}_2 \text{-N}) \\ &= [1.12 + 2.68 + (215.13 - 2.68)] \times 500 = 108 \text{ g N} \end{aligned}$$

Nitrogen in tilapia biomass can be calculated according to Mutita (2003). Weight of tilapia on harvesting day was 13,612 g. Thus, nitrogen in tilapia biomass was;

$$\text{Nitrogen in tilapia} = (13,612)(0.6)(0.4887)(0.6) = 117.39 \text{ g N}$$

C-6 Calculation of Ammonia Removal rate (Aslan and Kapdan, 2006)

$$V = \frac{S_0 - S_t}{T_0 - T_t}$$

The rate of change in substrate (ammonium) concentration is described by the expression above, where V represents the ammonia removal rate ($\text{mg N m}^{-2} \text{ day}^{-1}$); S_0 is the initial ammonia concentration (mg N L^{-1}); and S_t is the corresponding ammonia concentration at time T_t (day). The relationship between ammonia concentration (S) and ammonia removal rate (V) was plotted. In theory, variation of ammonia removal

rate depends on ammonia concentration and can be calculated by the following equation;

$$V_{cal} = \frac{V_{max}S}{K_m + S}$$

where V_{max} is the maximum ammonia removal rate ($\text{mg N m}^{-2} \text{ day}^{-1}$); S is the ammonia concentration (mg N L^{-1}), and K_m is the half saturation constant (mg N L^{-1}). For example, the calculation of ammonium removal rate of shrimp diet acclimated Biocord™ biofilter subjecting to $10 \text{ mg N L}^{-1} \text{ NH}_4\text{Cl}$ can be illustrated in Table C-1. The calculation of the maximum ammonia removal rate (V_{max}) and the coefficient (K_m) can be done by plotting S vs. S/V . After fitting, the slope is $1/V_{max}$ while x-axis interception is $-K_m$. Figure C-1 and C-2 demonstrate that V_{max} and K_m from biofilters acclimated with $10 \text{ mg N L}^{-1} \text{ NH}_4\text{Cl}$ were $133.33 \text{ mg N m}^{-2} \text{ day}^{-1}$ and 5.4 mg N L^{-1} , respectively.

Table C-1 Show ammonia concentration, S and ammonia removal, V rate and S/V

Ammonia, [S] (mg N L^{-1})	V_{cal} ($\text{mg N m}^{-2} \text{ day}^{-1}$)
0.0	0
0.5	11.30
1.0	20.83
1.5	28.98
2.0	36.04
2.5	42.19



Table C-2 Show ammonia concentration, S and ammonia removal rate, V_{cal} from calculation.

Time, hrs.	Ammonia, [S] (mg N L ⁻¹)	Ammonia removal, V (mg N L ⁻¹ hr ⁻¹)	Ammonia removal, V (mg N m ⁻² day ⁻¹)	[S]/V (/day)
0	1.5617	0.04	22.47	0.07
11	1.0812	0.09	44.99	0.02
22	0.1627	0.01	4.17	0.04
36	0.0493	0.00	1.10	0.04
47	0.0246	0.00	0.63	0.04
66	0.0012	0.00	0.03	0.05
91	0.0000	0.00	0.00	0.00
116	0.0000	0.00	0.00	0.00
141	0.0000	0.00	0.00	0.00
165	0.0000	0.00	0.00	0.00

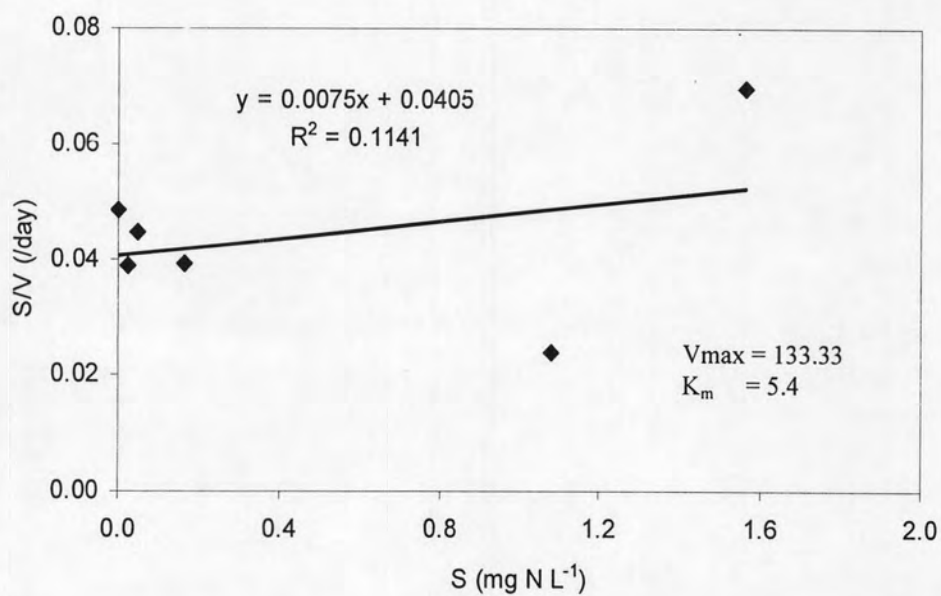


Figure C-1 Plotting of S versus S/V; S was the concentration of ammonia and V was the ammonia removal rate.

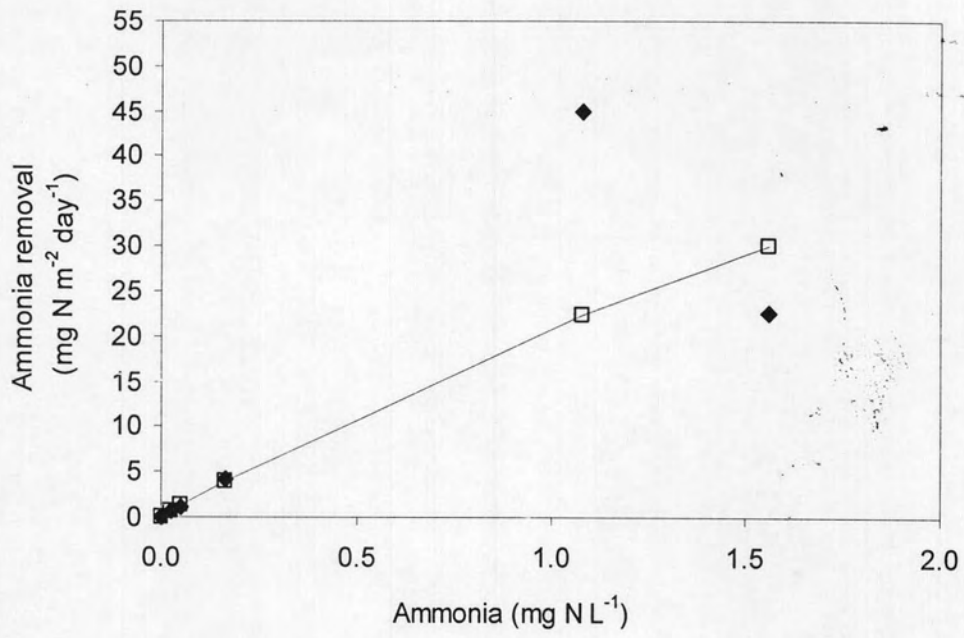


Figure C-2 Relationship between ammonia concentration and ammonia removal rate.

BIOGRAPHY

Mr. Thanathon Sesuk was born on November 8, 1977 in Prajinburi Province, Thailand. He received primary and secondary education at Watklongkae School and Chitchaichuen School in Prajinburi Province, respectively. He finished the Bachelor degree in Chemical Engineering from Department of Chemical Engineering, Faculty of Engineering, King Mongkut's University of Technology North Bangkok in 2000. He continued his further study in a Master Degree in Chemical Engineering at the Faculty of Engineering, Chulalongkorn University in 2007. During his master degree, Mr. Sesuk worked under various funding from the Thailand Research Fund, the National Innovation Agency, and Manit Farm. The results from his thesis were presented at the following:

Thanathon, S., Powtongsook, S. and Kasidit, N. Inorganic nitrogen control in a novel zero-water exchanged aquaculture system integrated with airlift-submerged fibrous nitrifying biofilters. Bioresource Technology 100 (2009) : 2088 - 2094.

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