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Benchmarking tilapia aquaculture systems in Egypt: characteristics, sustainability outcomes and entry points for sustainable aquatic food systems

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Data for Sustainable Intensification of Aquaculture System – Aquatic Food System Transformation

The lack of robust and coherent data on Aquaculture Systems performance is a fundamental barrier to realizing AqFS transformation.

Need for better data for sustainable intensification

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In recent years, multiple actors have pointed out the need to develop a solid evidence base and reliable statistics about the **characteristics and performance** of aquatic food systems, as a means of **enhancing their short- and long-term sustainability** (Farmery et al., 2021; WorldFish et al., 2020; Mikkelsen et al., 2020).

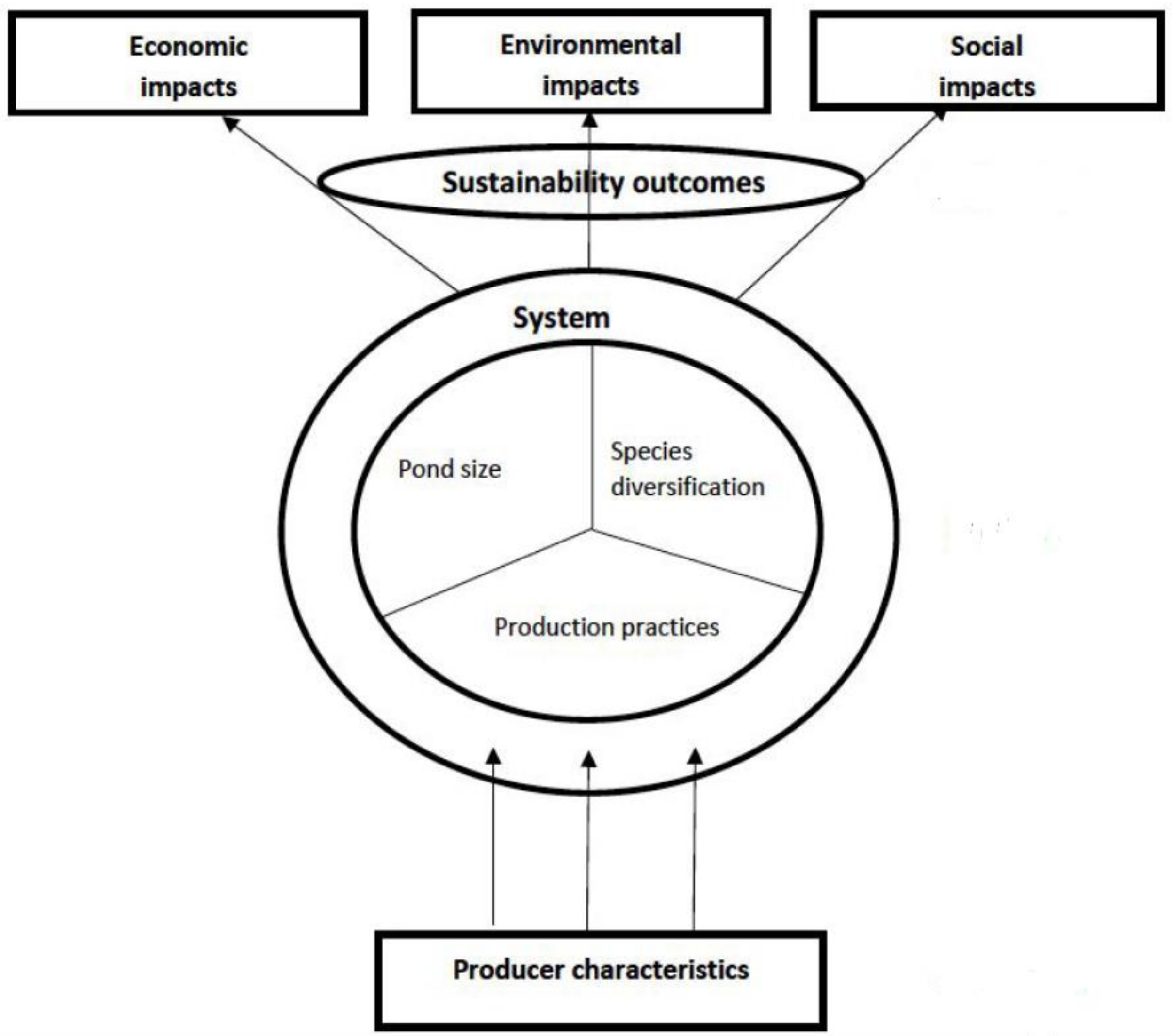
Among others, such information is crucial **for informed and transparent decision-making** (Bush et al, 2021), not the least to **support investments for facilitating the adoption and diffusion of suitable innovation packages** (Lasner et al., 2017, Shikuku et al., 2021) that **can catalyze the transitioning to a sustainable, equitable, inclusive and resilient food system** (FAO, 2020).

An interesting case....Tilapia farming in Egypt

- In Egypt, fish production and aquatic food systems play a major role for the food security and nutrition of a large fraction of the population, as well as of the broader economy (FAO, 2020).
- Despite its success, the Egyptian tilapia sector faces multiple sustainability challenges at local and international level.
- There is a real need to understand the sustainability performance of the sector.
- **General lack of robust information about the characteristics, performance and trade-offs of tilapia farming systems in the country** that can inform policy decisions and investors on the requirements to achieve sustainable intensification, and thus how to enhance sustainability.

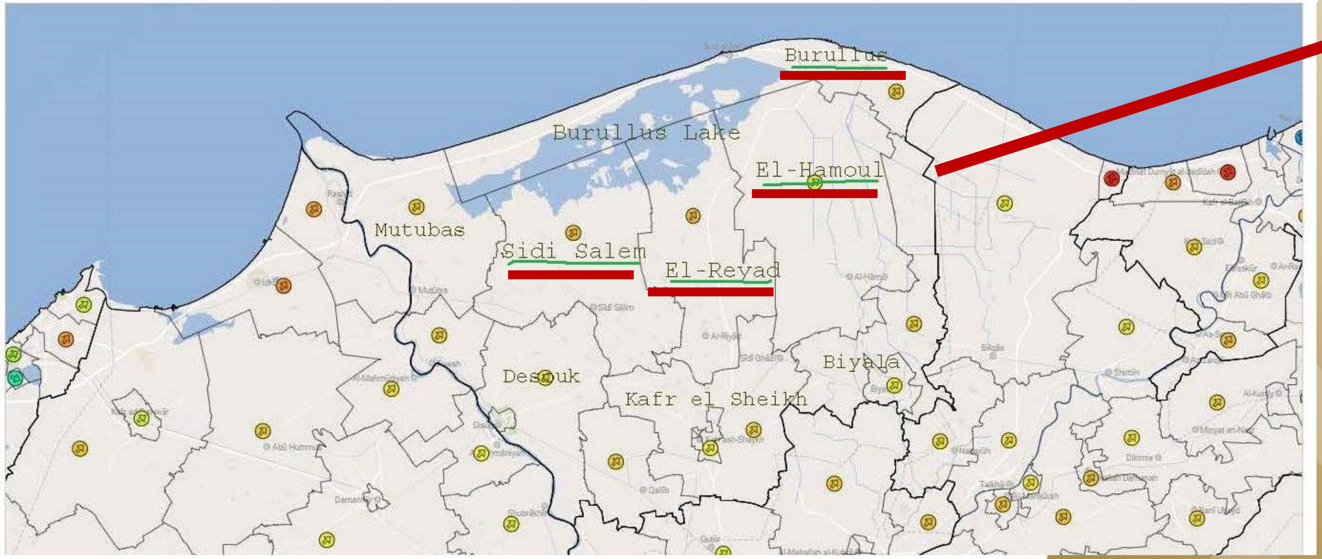
Conceptual Framework

- We refer to food and nutrition security, economic performance, and environmental impacts as crucial dimensions of sustainable food systems, including of aquatic food systems.
- Accordingly, we assess the performance of tilapia systems on (a) economic performance, (b) food security, (c) freshwater consumption, and (d) greenhouse gas emissions.



Study area - Kafr El Sheikh Governorate

Four districts (Markaz), namely Burullus, El Hamoul, El Ryad, and Sidi Salm, were purposively selected because of their importance in tilapia aquaculture.



Sampling and data collection

Farm-level data were collected from farm owners and managers, using a pre-tested digital questionnaire.

A total of 402 respondents from tilapia farming households in Kafr El Sheikh governorate participated in the survey in September–December 2019.

Within each of the four target districts, three separate lists of tilapia farmers were compiled, and stratified by aquaculture farm size (<4.2 ha, 4.2–10 ha, and >10 ha).

Sustainability outcomes

The first sustainability outcome variable is **gross margins** and reflects economic performance.

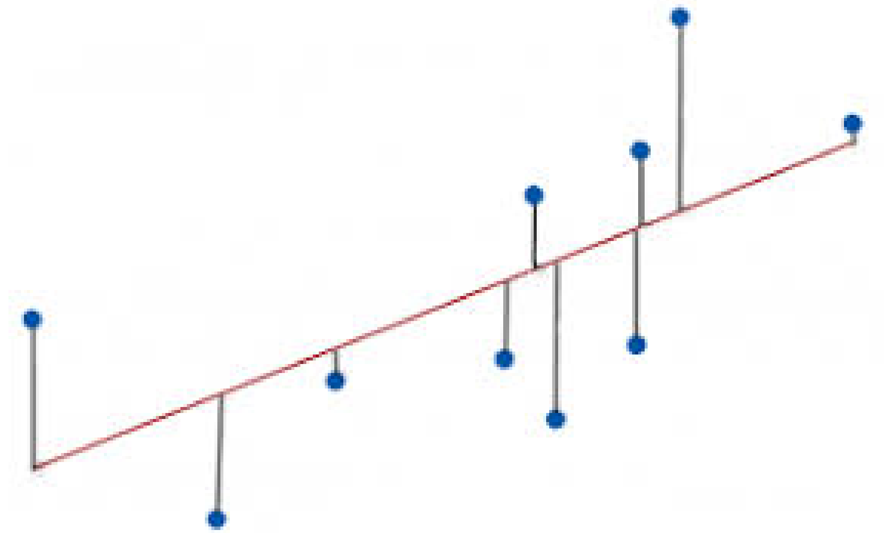
The second sustainability outcome variable is the **food consumption score (FCS)**, which is a proxy of food security. The FCS is a measure of dietary diversity and is based on the recall of the distinct types of food consumed within a household in the previous 7 days (Ramakrishnan et al., 1999).

The remaining two sustainability outcomes relate to the environmental dimension. The first one is **freshwater consumption (FWC)**, which consistent with existing literature (e.g., Henriksson et al., 2017) is calculated as: $FWC = (evaporation\ rate\ x\ total\ pond\ area\ x\ length\ of\ cycle)$.

The second outcome is the **feed conversion ratio (FCR)** measured by dividing the total quantity of feed (kg) by the quantity of harvested fish (kg). We use this as a proxy of different environmental impacts, as feed is the main driver behind global warming, eutrophication, and other impacts (Henriksson et al. 2017).

Material and Methods

Estimating **ordinary least squares (OLS) regression** to assess the marginal contribution of each treatment variable on the four outcome variables. Aquaculture systems and practices are likely to influence economic, social, and environmental outcomes differently depending on the level of the outcomes. OLS estimates are useful to show marginal contributions of aquaculture systems to economic, food security, and environmental outcomes.



OLS is useful to descriptively assess the marginal contribution of tilapia aquaculture systems, self-selection imply that parameter estimates will be biased unless unobserved heterogeneity is controlled for.

Propensity score matching (PSM)

We use propensity score matching (PSM) to estimate the causal effects of the tilapia aquaculture systems and practices.

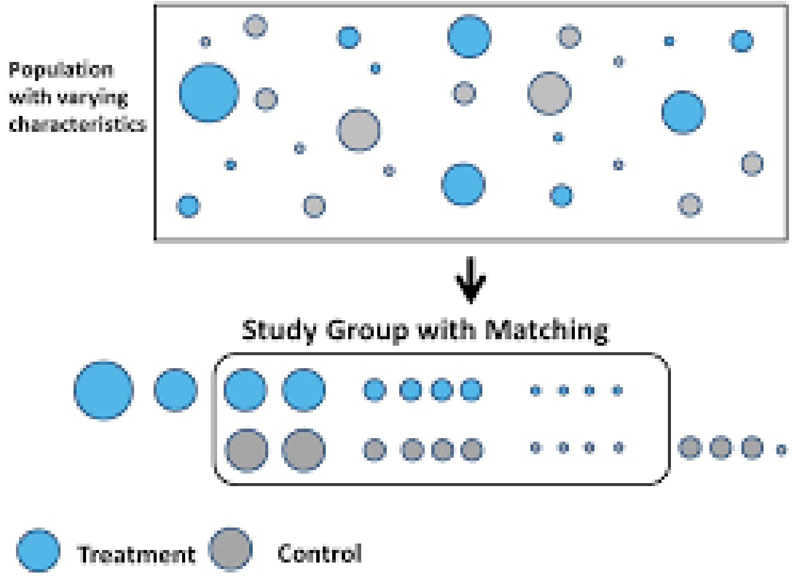
Matching models simulate the conditions of an experiment in which adopters of a particular culture system or farming practice and non-adopter households are randomly assigned, allowing for the identification of a causal link between culture system or farming practice choice and measures of performance.

3 treatments:

1 - type of culture system - Polyculture (t) and Monoculture (c)

2 – feeding practices - (a) pellet feed only; (b) extruded feed only; and (c) both pellet and extruded feed

3- stocking density (number of fingerlings stocked per square meter) - (a) 0.24–2.98 fingerlings m-2; (b) 3.02–3.57 fingerlings m-2; and (c) 3.67–7.14 fingerlings m-2



Sample household characteristics

Variable	Description	Mean / proportion
Age	Age of the respondent (years)	44.31 (11.02)
No formal education	1=farmer has no formal education; 0=otherwise	0.14 (0.34)
Primary education	1=farmer has primary education; 0=otherwise	0.15 (0.36)
Preparatory education	1=farmer has preparatory education; 0=otherwise	0.13 (0.34)
Secondary education	1=farmer has secondary education; 0=otherwise	0.45 (0.50)
Tertiary education	1=farmer has tertiary education; 0=otherwise	0.13 (0.34)
Sex	Sex of the respondent (1=male; 0=female)	0.99
Manager	Role of the respondent on the farm (1=owner; 0=manager)	0.84 (0.37)
Experience	Respondents experience in fish farming (years)	17.52 (9.36)
Polyculture	1=farmer practices polyculture; 0=otherwise	0.82
Risk	Farmer’s attitude towards risk (score)	4.94 (1.87)
Weather	1=farmer had access to weather information; 0=otherwise	0.05 (0.21)
Credit	1=farmer had access to credit; 0=otherwise	0.01 (0.11)
Group	1=farmer participated in a farmers’ association; 0=otherwise	0.08 (0.27)
Farm size	Size of land under aquaculture (acre)	5.39 (4.45)

Notes: Standard deviations in parentheses.

Stocking and yield of tilapia, by species diversification and pond size

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Variable	Species diversification			Size of pond (ha)			
	Monoculture	Polyculture	p-value	<4.2	4.2–10	>10	p-value
Stocking density (pieces m^{-2})	3.9 (1.2)	3.4 (1.0)	0.001	3.5 (1.1)	3.4 (1.0)	3.8 (1.2)	0.134
Weight at stocking (g)	1.5 (3.0)	2.5 (4.0)	0.014	2.1 (3.6)	2.8 (4.5)	2.1 (3.8)	0.289
Weight at harvesting (g)	339.9 (91.0)	322.3 (97.0)	0.141	323.7 (93.4)	326.6 (99.2)	333.1 (103.6)	0.817
Survival rate (%)	79.7 (19.9)	78.4 (18.4)	0.625	79.6 (17.7)	77.5 (19.9)	76.5 (20.8)	0.439
Yield (kg ha^{-1} per cycle)	10,460.5 (3,230.1)	8,404.7 (2,852.6)	0.000	8,969.4 (3,175.6)	8,272.7 (2,777.0)	8,963.1 (2,695.7)	0.126
Number of observations	74	328		247	107	48	

Notes: In parentheses are standard deviations. For analysis by culture system, p-value is a t-test of difference in means. For analysis by size of pond, p-values are results of analysis of variance (ANOVA)

OLS regression estimates of the effect of different tilapia production activities on sustainability outcomes

	Gross margins (USD/kg tilapia)		Food Consumption Score		Fresh water consumption		Feed Conversion Ratio	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Survival rate	0.21^{**} (0.09)	0.021	3.82^{***} (1.68)	0.023	5.80 (1.70)	0.001^{***}	-0.19 (0.05)	0.001^{***}
Stocking density (3.02–3.57 fingerlings m^{-2})	0.04 (0.12)	0.719	-0.98 (2.02)	0.627	3.33 (1.57)	0.035^{**}		
Stocking density (3.67–7.14 fingerlings m^{-2})	0.19^{*} (0.11)	0.083	4.48^{***} (2.36)	0.058	9.86 (2.74)	0.000^{***}		
Size of fingerlings (0.3–0.5g)	-0.27^{***} (0.09)	0.003	12.65^{***} (1.77)	0.000	5.25 (1.99)	0.009^{***}		
Size of fingerlings (0.75–3g)	-0.93^{***} (0.19)	0.000	14.36^{***} (3.46)	0.000	-1.80 (1.89)	0.342		
Size of fingerlings (>4g)	-0.06 (0.18)	0.747	14.60^{***} (2.69)	0.000	2.18 (2.70)	0.421		
Feed type = pellet only	-0.61^{***} (0.22)	0.005	-7.37 (6.67)	0.270	-4.71 (2.77)	0.090^{*}	1.02 (0.32)	0.002^{***}
Feed type = extruded only	-0.67^{***} (0.15)	0.000	-2.00 (4.72)	0.673	0.57 (2.48)	0.819	0.90 (0.28)	0.001^{***}
Feed type = both pellet & extruded only	-0.74^{***} (0.25)	0.003	0.94 (5.46)	0.863	2.76 (2.89)	0.341	0.97 (0.30)	0.001^{***}
Polyculture	-0.09 (0.11)	0.429	2.17 (2.26)	0.336	0.32 (2.29)	0.889	0.23 (0.04)	0.000^{***}
Applies chemicals	-0.56^{***} (0.18)	0.002	-0.03 (2.95)	0.991	0.36 (2.16)	0.870	0.19 (0.13)	0.154
Applies fertilizer	0.10 (0.12)	0.375	0.93 (1.95)	0.634	-0.22 (1.64)	0.892	0.01 (0.06)	0.869
Medium scale farmer (4.2–10ha)	0.04 (0.11)	0.681	2.54 (1.79)	0.156			-0.14 (0.06)	0.027^{**}
Large scale farmer (>10ha)	-0.03 (0.17)	0.869	6.78^{**} (2.98)	0.023			-0.04 (0.09)	0.636
Stress-tolerant strains	0.36^{***} (0.12)	0.004	14.57^{***} (3.88)	0.000	0.11 (2.64)	0.966	-0.11 (0.09)	0.221
Proper size of fingerlings	0.53^{*} (0.30)	0.073	-2.49 (4.93)	0.614	27.32 (4.81)	0.000^{***}	-0.49 (0.22)	0.027^{**}
Improved feeding	-0.21 (0.21)	0.315	21.21^{***} (3.95)	0.000	-1.61 (3.33)	0.629	-0.03 (0.14)	0.821
Improved water management	-0.05 (0.22)	0.814	2.55 (12.73)	0.842	6.95 (10.16)	0.495	-0.11 (0.21)	0.589
Improved fish health management	0.03 (0.32)	0.916	-8.52 (5.44)	0.118	-36.51 (3.36)	0.000^{***}	0.01 (0.22)	0.947
Observations	402		402		322		402	
Pseudo R-squared	0.18		0.30		0.15		0.16	

Propensity Score Matching Results

Impact of species diversification on sustainability outcomes

Outcome / treatment variable	Treated	Control	ATT	t-statistic
Tilapia yield	8,420	10,612	-2,192	-4.64***
Variable cost kg^{-1} of tilapia	1.30	0.92	0.38	4.89***
Gross margins kg^{-1} of tilapia	0.45	0.70	-0.25	-1.87*
Benefit-cost ratio	1.81	2.23	-0.42	-1.68*
Food consumption score	43.93	40.93	3.00	1.00
Fresh water consumption	11.21	14.54	-3.32	-1.16
Feed conversion ratio	1.42	1.17	0.25	4.42

Impact of feeding practices on sustainability outcomes

Outcome / treatment variable	Treated	Control	ATT	t-statistic
Panel A: Pellet feed only				
Tilapia yield	7,220.81	8,912.33	-1,691.52	-2.33***
Variable cost kg^{-1} of tilapia	0.89	1.17	-0.28	-2.04**
Gross margins kg^{-1} of tilapia	0.63	0.60	0.03	0.16
Benefit-cost ratio	1.81	1.87	-0.06	-0.32
Food consumption score	35.25	42.51	-7.26	-1.20
Fresh water consumption	4.26	9.15	-4.89	-2.53***
Feed conversion ratio	1.43	1.47	-0.04	-0.21
Panel B: Extruded feed only				
Tilapia yield	9,025.54	7,797.03	1,228.51	3.14***
Variable cost kg^{-1} of tilapia	1.20	1.22	-0.01	-0.06
Gross margins kg^{-1} of tilapia	0.51	0.53	-0.02	-0.13
Benefit-cost ratio	1.87	1.92	-0.05	-0.32
Food consumption score	42.66	45.96	-3.30	-1.30
Fresh water consumption	12.07	7.57	4.50	3.20***
Feed conversion ratio	1.37	1.38	-0.01	-0.08
Panel C: Pelleted & extruded feed				
Tilapia yield	7,542.90	8,857.27	-1,314.37	-2.86***
Variable cost kg^{-1} of tilapia	1.50	1.11	0.39	1.64*
Gross margins kg^{-1} of tilapia	0.30	0.58	-0.28	-1.26
Benefit-cost ratio	1.76	1.85	-0.09	-0.66
Food consumption score	49.87	42.34	7.53	2.78***
Fresh water consumption	9.24	13.02	-3.78	-1.86*
Feed conversion ratio	1.55	1.36	0.19	1.34

Impact of stocking density on sustainability outcomes

Outcome / treatment variable	Treated	Control	ATT	t-statistic
Panel A: Stocking density (0.24–2.98 fingerlings m^{-2})				
Tilapia yield	7,198.68	10,078.33	-2,879.65	-9.02***
Variable cost kg^{-1} of tilapia	1.27	1.08	0.19	1.60
Gross margins kg^{-1} of tilapia	0.45	0.67	-0.22	-1.81*
Benefit-cost ratio	1.79	2.09	-0.30	-2.49***
Food consumption score	43.93	44.38	-0.45	-0.21
Fresh water consumption	7.83	13.67	-5.84	-3.14***
Feed conversion ratio	1.53	1.28	0.25	3.46***
Panel B: Stocking density (3.02–3.57 fingerlings m^{-2})				
Tilapia yield	9,149.03	8,557.07	591.96	1.66*
Variable cost kg^{-1} of tilapia	1.25	1.22	0.03	0.31
Gross margins kg^{-1} of tilapia	0.50	0.49	0.01	0.07
Benefit-cost ratio	1.99	1.81	0.18	1.19
Food consumption score	39.66	45.20	-5.54	-2.58***
Fresh water consumption	9.87	13.01	-3.14	-1.65*
Feed conversion ratio	1.28	1.44	-0.16	-2.98***
Panel C: Stocking density (3.67–7.14 fingerlings m^{-2})				
Tilapia yield	10,107.95	8,173.85	2,064.24	5.86***
Variable cost kg^{-1} of tilapia	1.14	1.24	-0.10	-1.17
Gross margins kg^{-1} of tilapia	0.56	0.49	0.07	0.71
Benefit-cost ratio	1.85	1.87	-0.02	-0.15
Food consumption score	46.26	41.74	4.52	2.01**
Fresh water consumption	16.92	10.59	6.33	2.70***
Feed conversion ratio	1.30	1.37	-0.07	-1.20

Benchmarking tilapia aquaculture systems in Egypt

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This study provides a robust benchmark on the current status of tilapia aquaculture in Egypt, and its sustainability outcomes.

Most previous studies on the performance of tilapia systems have mainly focused on economic outcomes such as productivity and profitability.

Our study has shown that beyond differentiated economic outcomes, differences in the characteristics and practices/activities of tilapia aquaculture systems have broader ramifications for other sustainability outcomes such food security and environmental performance.

Collectively, this rich analysis provides a strong direction **to move from mono-dimensional surveys to holistic integrated approaches to assessments and data in order to gain an enhanced understanding of the dynamic functioning of aquaculture systems**.

Balancing the synergies and trade-offs of sustainable aquaculture

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The integrated analysis conducted in this study has shown that there are synergies and trade-offs, both between and within the three sustainability outcome dimensions considered: economic, social, and environmental.

These trade-offs possibly suggest that a more responsible and realistic approach to a sustainable aquaculture system (and its intensification) would be to recognize that the achievement of win-win situations is not always straightforward and that **difficult socioeconomic political choices must be made to minimize trade-offs**.

The findings further suggest the need to **consider multiple outcomes even within a specific dimension of sustainability when assessing the impacts of aquaculture systems and practices**.

Policy implications and recommendations

- **Rationalize feed management, cost and quality**
- **Support the adoption of Better or Improved Management practices.**
- **Develop an efficient production strategy to maximize economic benefits, reduce negative environmental impacts and support food security.** Therefore, it is necessary to develop investments and actions to support the adoption of optimal stocking rates and size at stocking, and optimal species composition in production ponds (monoculture vs polyculture).
- **Co-develop replicable approaches to characterize and benchmark aquaculture systems.**

Thank you!

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