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Ecological strategies for reusing aquaculture water in agriculture

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Abstract:

This study evaluates the feasibility of using fish farm effluent as a substitute for chemical fertilizers in maize cultivation. Four treatments were applied: T0 – freshwater (control), T1 – fish farm effluent, T2 – water + mineral fertilizer, T3 – fish effluent + nitrogen supplementation. Key growth parameters (width, vigor, number of leaves) were measured at early and late developmental stages. ANOVA results indicated no statistically significant differences among treatments for all measured parameters ($p > 0.05$). Maize irrigated with fish farm effluent (T1) showed slightly higher early growth (width = 47.2 mm, vigor = 8.77, leaves = 5) compared to T0 (width = 52.8 mm, vigor = 10.33, leaves = 6), while T2 and T3 treatments had similar trends. Effluent treatments provide essential nutrients (N, P, K), supporting initial growth and promoting circular agriculture. This approach may reduce synthetic fertilizer use, lower production costs, and decrease environmental pollution. The study highlights fish farm effluent as a sustainable irrigation source for maize.

1. Introduction

Increased use of chemical fertilizers in agriculture and more intensive agricultural operations have resulted in a number of negative impacts on the environment, including pollution of soils and depletion of T_0 resources. There is also an increase in eutrophication of aquatic ecosystems as a result of exposure to mineral fertilizer [1 , 2]. The application of mineral fertilizers does improve crop productivity; however, the overuse of these products has resulted in the depletion of many natural resources and increased costs to the agricultural industry, especially in the case of arid and semi-arid areas with limited access to fresh water [2].

As a result, rising water scarcity and the increasing global interest in sustainable agriculture has resulted in an increase in interest in integrated farming systems that reuse aquaculture by-products to reduce waste and promote sustainability [3]. Aquaculture waste (also referred to as aquaponics) can be defined as the discharge of water from fish farms and the waste produced by fish farms in the form of sewage. Aquaculture waste has been found to be an optimal source for supplying essential nutrients like nitrogen (N), phosphorus (P), and potassium (K) from fish feces and uneaten feed remains [4].

Research indicates that by using the effluents produced through aquaculture treatments as a method of irrigation, it is possible to create enhanced yield, increase water-use efficiencies, and lessen the reliance on synthetic fertilizers. An example of this type of practice is irrigation of maize with tilapia effluent, which have both provided increased production over traditional forms of irrigation [5]. Furthermore, these systems help create circular economy type systems since the water that is utilized for fish farming can then be reused to irrigate crops, which minimizes wastage, pollution, and degradation of the natural environment [6,7] . The goals of this research project are to assess whether or not tilapia pond water used as an irrigation source for maize will provide sustainable yields; determine the effects of tilapia pond water based irrigation on agro-economic factors; and provide viable alternatives to synthetic fertilizer uses, while promoting sustainable management of nutrient and water resources.

2. Materials and Methods

2.1 Experimental Site and Soil

The experiment occurred between April and June 2025. Maize was grown in soil characterized as sandy loam, pH 7.2, organic matter 2.1%, initial N = 0.15%, P = 15 mg/kg, K = 110 mg/kg, each treatment had 3 replicates.

Table 1. Initial physicochemical characteristics of the experimental soil.

Soil parameters	Value
Soil texture	Sandy Loam
pH	7.2
Organic matter	2.1 %
Initial nitrogen (N)	0.15mg/kg
Initial phosphorus (P)	15mg/kg
Initial potassium (K)	110mg/kg
Replicates per treatment	3

2.2 Experimental Site

The experiment occurred between April and June of 2025. Fish were reared in 400-L tanks , where their average weight was approximately 100 g. Throughout the experiment, the fish were fed a nutrient-dense diet formulated to provide essential nutrients (protein, lipid, and mineral) and the fish were fed twice daily.“Fig. 1” shows The tilapia feed includes a high protein level, high energy level, a moderate fat level, and moderate-fiber level and adequate minerals.

Figure 1: Feed fish of tilapia

"Table 2". The inclusion of these high-quality ingredients provides a feed type that supports the growth of tilapia and the production of nutrient-rich effluent that can be used as irrigation water in integrated aquaculture–agriculture farming systems.

Table 2: Biochemical Composition of Tilapia Feed

Biochemical Composition	%
Crude Protein	38
Crude fat	10
Crude Fibre	9
Ash	10
Phosphore	1
Calcium	1
Supplements (Vitamins , Minerals)	31
Energy	363 kcal

2.3 Monitored Parameters

To investigate the impact of a variety of irrigation and fertilization applications on maize production, the research article evaluated a number of significant factors: Growth Rate of the Plant; Leaf coloration; The presence of signs that indicate the existence of nutritional deficiencies in the crop; and The general condition of all crops during their growth cycle. These parameters were used to evaluate plant health and development. to evaluate the health status and level of development of plants, as well as to determine whether irrigation and fertilization methods used are effective. The article includes information from four separate experiments that used daily irrigation and included four different irrigation and fertilization applications to test the effects on maize.

2.4 Experimental treatments:

First Test of this Study: the corn crop was watered with freshwater all the way through. Second Test of this Study: the corn crop was watered with water obtained from a soilless dry-farming technique. Third Test of this Study: the corn crop was watered with fish-farming-derived water. Fourth Test of this Study: the corn crop was watered with fertilizer.

3. Results and discussion

Table 3 : Results of the measured parameters

Date	PLANT	Symbol	Width (mm)	Vigor (mm)	Irrigation (ml)	Color degrees	Number of leaves	Temperatur (C)
21-04-2025	Freshwater (control)	T0	27	8.8	100	4.5	4	24
	Fish farm effluent	T1	32.5	8	100	4.5	5	24
	Water + mineral fertilizer	T2	32.5	8	100	4.5	5	24
	Fish effluent + nitrogen supplementation	T3	39	8.7	_	4.5	4	24
23-04-2025	Freshwater (control)	T0	29.5	8.87	200	4.5	4	26
	Fish farm effluent	T1	34	9	200	4.5	5	26
	Water + mineral fertilizer	T2	34.5	9	200	4.5	5	26
	Fish effluent + nitrogen supplementation	T3	39	8.7	_	4.5	4	26
24-04-2025	Freshwater (control)	T0	31	8.87	250	4	4	25
	Fish farm effluent	T1	34.9	9	250	4	5	25
	Water + mineral fertilizer	T2	37	9	250	4	5	25
	Fish effluent + nitrogen supplementation	T3	39	8.7	_	4	4	25
25-04-2025	Freshwater (control)	T0	32	8.87	300	4.5	4	27
	Fish farm effluent	T1	36	9	300	4.5	5	27
	Water + mineral fertilizer	T2	37	9	300	4.5	5	27
	Fish effluent + nitrogen supplementation	T3	39	8.7	_	4,5	4	27
27-04-2025	Freshwater (control)	T0	35	9.11	300	4.5	5	23
	Fish farm effluent	T1	39	7.61	300	4	4	23
	Water + mineral fertilizer	T2	37.5	7.49	300	4	4	23
	Fish effluent + nitrogen supplementation	T3	42	8.71	_	3.5	4	23
28-04-2025	Freshwater (control)	T0	38.5	9.12	300	4,5	5	24

	Fish farm effluent	**T1**	41.4	7.88	300	4	4	24
	Water + mineral fertilizer	**T2**	39	7.5	300	4	4	24
	Fish effluent + nitrogen supplementation	**T3**	43	8.88	_	3.5	4	24
29-04-2025	**Freshwater (control)**	**T0**	40	9.60	100	4.5	5	24
	Fish farm effluent	**T1**	43	8.23	150	3,5	4	24
	Water + mineral fertilizer	**T2**	38	7.15	150	4	4	24
	Fish effluent + nitrogen supplementation	**T3**	41		_	3	4	24
30-04-2025	**Freshwater (control)**	**T0**	42,5	9.37	100	4.5	5	22
	Fish farm effluent	**T1**	45.3	8.25		3.5	4	22
	Water + mineral fertilizer	**T2**	39.5	7.53		4	4	22
	Fish effluent + nitrogen supplementation	**T3**	44.8	8.95	_	3	4	22
31-04-2025	**Freshwater (control)**	**T0**	45.4	9.74	100	4.5	5	21
	Fish farm effluent	**T1**	47.2	8.14	100	4	4	21
	Water + mineral fertilizer	**T2**	46.5	9.14	_	4	4	21
	Fish effluent + nitrogen supplementation	**T3**	45	_	_	3.5	4	21
01-05-2025	**Freshwater (control)**	**T0**	48	9.8	_	4.5	5	22
	Fish farm effluent	**T1**	49	8.19	100	4	5	22
	Water + mineral fertilizer	**T2**	47.5	9.21	100	4	4	22
	Fish effluent + nitrogen supplementation	**T3**	45.6	8.96	_	3.5	5	22
03-05-2025	**Freshwater (control)**	**T0**	52.8	10.33	100	4.5	6	22
	Fish farm effluent	**T1**	46.2	8.77	100	4	5	22
	Water + mineral fertilizer	**T2**	48.2	9.39	100	3.5	4	22
	Fish effluent + nitrogen supplementation	**T3**	45.9	9.11	_	3	5	22

Table 4 : Analysis of Variance (ANOVA) Results for the Effects of Treatment on Plant Width, Vigor, and Number of Leaves.

Parameters	Source	df	F-value	P-Value
Width	Treatment	3	=1,1	>0,05
Vigor	Treatment	3	n.s	>0,05
Number of leaves	Treatment	3	n.s	>0,05

The results of the analysis of variance (ANOVA) for the three measured factors width, vigor, and number of leaves affected by the different treatments are summarized in the table. The statistical analysis was performed to determine whether the applied treatments had significant effects on these plant growth parameters.

Width: The F statistic for width was 1.1, with a p-value greater than 0.05. This indicates that there were no statistically significant differences in plant width among the treatments. In other words, the application of different treatments did not lead to measurable changes in plant width at the alpha level of 0.05.

Vigor: For plant vigor, the F statistic was reported as not significant (n.s.) with a p-value exceeding 0.05. This suggests that the treatments did not produce significant variations in the overall vigor or growth robustness of the plants. The lack of statistical significance implies that any observed differences in vigor could be attributed to natural variability rather than the experimental treatments.

Number of leaves: Similarly, the analysis for the number of leaves yielded an F statistic marked as not significant (n.s.) with a p-value greater than 0.05. This result shows that the treatments did not significantly affect the leaf count of the plants compared to the control. The absence of a significant effect indicates that all treatment groups maintained similar foliar development.

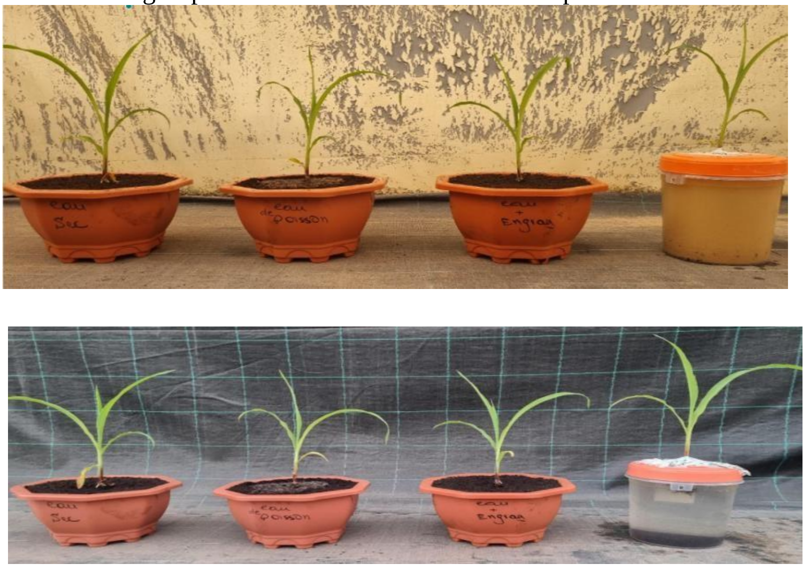

Figure 2 : Visual appearance of maize crops under different irrigation treatments

Table 3 summarizes the effects of irrigation treatments on maize growth at early and late developmental stages. early growth (April 21, 2025) and later growth

(May 3, 2025). During these two periods, we measured plant width, vigor, leaf color, number of leaves, irrigation application, and ambient temperature. Plants irrigated with freshwater showed the greatest increase in width; however, this difference was not statistically significant. giving them the advantage of faster growth compared to the other treatments. On the other hand, plants watered with T_1 and dry fertilizer started with a larger diameter, but their growth slowed down later on. This suggests that while their growth rate initially increased, it eventually plateaued.

T_0 irrigation produced the largest percentage increase in plant vigor, likely due to compensatory growth following the slow initial growth of the plants [8] . In contrast, the nutrient-enriched treatments maintained relatively constant high levels of vigor throughout the entire experiment, indicating continuous vigor and the presence of a good physiological state [8] . A slight decrease in leaf color intensity was observed in the nutrient-enriched treatments during the later stages of the experiment. This trend could indicate the onset of a mild nutrient deficiency, or it could reflect physiological adaptations due to rapid growth or increased nutrient uptake by the plants.

The largest percentage increase in leaf count occurred in plants irrigated with T0, further suggesting compensatory growth [8] .There was no significant difference in the number of leaves produced between the nutrient-enriched treatments and the number of leaves produced by the plants. For the nutrient-enriched treatments, there was a relatively more moderate or stable increase in the number of leaves produced compared to initial leaf production, followed by a decrease in the rate of leaf emergence during the later stages of the experiment .

The findings of this research indicate that the use of nutrient-enriched irrigation water from an aquaculture pond for tilapia farming and growth, according to the study by [8] had a more positive effect on the initial growth of maize plants than the use of T_0 alone for irrigation. Specifically, the increase in maize plant early growth response can be attributed to the higher concentrations of macronutriments such as nitrogen, phosphorus, and potassium present in aquaculture waste [9] . It has been shown that irrigation with aquaculture effluent leads to an increase in the amounts of N, P, and K in the soil and an accelerated growth rate of crops compared to irrigating crops with T_0 [8]. Enriched treatments, like those involving nutrient-rich aquaculture effluents, have been highlighted by researchers as a valuable source of nutrients. According to studies, these effluents, derived from aquaculture systems, offer a promising alternative for boosting plant health and growth [9] . It was also pointed out that aquaculture effluents serve as a valuable alternative source of essential nutrients for a range of agricultural uses, including livestock, garden vegetables, and other crops. This helps reduce reliance on traditional mineral fertilizers while boosting the overall vitality of the crops. [10, 11] further supported this, demonstrating that the rapid growth rates observed during the early stages of crop treatment with nutrient-enriched aquaculture effluents will not be sustained in the long term unless nutrient inputs are properly managed. This idea is confirmed by [12, 13], who found that the rapid depletion of nutrients in aquaculture effluents requires additional supplementation to ensure continued growth. Other studies have shown that aquaculture effluents can, at least temporarily, increase soil fertility; however, this benefit diminishes if nutrient sources are not replenished and maintained at appropriate levels over time [9] . Additionally, [14- 15] emphasized that water containing high nutrient levels used for irrigation must maintain a proper balance of macronutriments to avoid nutrient deficiencies or imbalances, especially during the later stages of plant development.

4. Conclusion

This study suggests that fish pond water may serve as an alternative to chemical fertilizers in maize irrigation. Early growth was slightly enhanced by effluent treatments due to N-P-K supply, but no significant differences were found among treatments. Using fish pond effluents can reduce reliance on synthetic fertilizers, decrease production costs, and support circular agriculture. Proper nutrient management is essential to maintain crop development and avoid deficiencies.

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